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STANDARD OF THE EUROPEAN JURASSIC

BY W. J. ARKELL

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ABSTRACT

The author advocates that the International Geological Congress should be asked to set up an International Commission on Stratigraphical Nomenclature charged with formulating a Code of Rules analogous with that which has brought order into zoological nomenclature. In this paper he proposes a draft Code of Rules and shows with what results it can be applied to the European Jurassic.

INTRODUCTION

Under the title *Standard of the Jurassic system* Dr. Siemon W. Muller (1941) published a courageous attempt to reconcile the conflicting opinions on the classification of the Jurassic system in Europe and to evolve a standard sequence acceptable to all workers in and outside Europe. Muller's tables will be found especially valuable for reference, and thorough consideration has been given to his scheme of classification.

Muller envisages that "future research might necessitate slight changes" in his tables, and he proposes that at some future date the scheme should be put to the International Geological Congress for its formal approval and recommendation. There

will be general agreement that this is the body which should eventually act; but before any approach is made to the Congress stratigraphers should consider very carefully what it is that they want to ask it to do. Most important is the question whether the Congress should approve and recommend (and thereby presumably standardize with legal authority) a ready-made scheme of nomenclature previously thrashed out by independent geologists, or whether they should be asked only to formulate a Code of Rules for geological nomenclature, in the same way as the International Zoological Congress long ago did for zoological nomenclature through its International Commission.

It might be highly undesirable to invest with legal authority any ready-made scheme of stages and zones, however carefully and conscientiously worked out, for no one is infallible (Marcou, 1898), and future research would almost certainly produce more and more differences of opinion and show up more and more errors in the stereotyped scheme. If, however, the Congress were to restrict itself to promulgating a Code of Rules, all future research, by objective application of the Rules, would lead to a progressively closer approximation to the ideal scheme desired, as has undoubtedly been the case in zoological nomenclature. (For the history of the setting up of the International Commission of Zoological Nomenclature by the Zoological Congress and the gradual working out of the scheme, *see* Hemming, 1943.)

It might be found that rules giving good results in one geologic system were unsuitable for another system, and eventually it would have to be decided whether a compromise code for all systems would be preferable to variations adapted to each system. (The serious difficulties over pirority in stage names in the Eocene, for instance, would require consideration: *see* Wrigley and Davies, 1937.) For this reason it would be desirable for the Congress to start with a committee for each geologic system. When these preliminary committees had reported, their representatives could be formed into a general committee charged with reconciling conflicting reports and, if possible, hammering out a scheme applicable to all systems.

The governance of stratigraphic nomenclature by the rule of priority was advocated by one of the greatest masters of Jurassic stratigraphy, M. Neumayr, over 70 years ago (Neumayr, 1873, p. 228).

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PROPOSED CODE OF RULES

STATEMENT OF PROBLEM

The problems of stratigraphic nomenclature are akin to those of zoological nomenclature. An approximation to uniformity of usage has been achieved in zoological nomenclature by the adoption of a Code of Rules. By analogy it is now suggested that the following rules could, with advantage, be adopted by stratigraphers in order

to produce standard sequences of stages and zones for at least the Jurassic and Cretaceous systems.

RULES FOR STAGES

(1) Stage names to be formed on place names, either modern or classical, and to end in -ian (French, -ien). (Rule 1 corresponds to the binomial rule in zoological nomenclature.) (a) Two stage names not to be derived from the same place: *e.g.*, Bolonian and Bononian (*Bononia* = Boulogne) cannot exist side by side, nor Bathonian and Bathian, Semurien, Sinemurien. In such cases the later variant to be regarded as a "stillborn homonym" of the earlier.[1]
(2) Rule of priority of publication (subject to Rule 3).
(3) Backward limit in time to be the year 1850. (Rule 3 corresponds to that which makes 1758 the starting point of binomial nomenclature in zoology.)
(4) Suspension of the rules to be resorted to by agreement in special cases where the letter of the law would cause unnecessary confusion or where "household words" would unnecessarily have to be replaced (as in zoologic nomenclature).

RULES FOR ZONES

(1) Zonal indices to be single ammonite species. (Exceptions would have to be made for certain formations, such as the Chalk.)
(2) Rule of priority of publication, subject to the index species in question: (a) occurring in the faunal province for which it is required to be used; and (b) being appropriate (*i.e.*, not excessively rare nor of excessively long vertical range).
(3) Publication of a zonal index to be strictly interpreted as dating from its first citation coupled with the word "zone". (Many indices appeared in the literature long before as indices of beds only; *e.g.*, *Gigas-Schichten*, *Couches à Ammonites plicatilis*).
(4) Subsequent renaming of a fossil not to deprive it of its priority as a zonal index. (*E.g.*, the index species of Oppel's Mutabilis zone (1863) was *Ammonites mutabilis* D'Orbigny, subsequently renamed *A. pseudomutabilis* De Loriol (1874) because found not to be the *A. mutabilis* of Sowerby; the name of the zone is therefore the Pseudomutabilis zone, although it had in the meantime sometimes been called after another species, the Eudoxus zone. Nor is the true *A. mutabilis* Sowerby thereby disqualified from becoming index of another zone, the Mutabilis zone of Salfeld, 1913).
(5) Suspension of the rules in special cases (as in Stage Rule 4).

STAGES

D'ORBIGNY'S STAGES

The stratigraphic work that corresponds to Linnaeus' *Systema Naturae* (10th ed., 1758) is unquestionably D'Orbigny's *Paléontologie Française, Terrain Jurassique*,

[1] When the earlier stage name is itself an invalid synomym and the later name formed on the same place is sufficiently distinct to obviate confusion, the latter might well be allowed: *e.g.*, Carixian (from *Carixa*, Charmouth, Lang 1913) should not be invalidated by Charmouthian Meyer Eymar (1864), a synonym of Pliensbachian, Oppel (1858).

(vol. i, Céphalopodes, 1842–51) in which the stages and zones were first enunciated and a complete stratigraphic system worked out for the Jurassic. The cataclysmic bias of D'Orbigny's work cannot invalidate its results. The relevant part of the book is the *Résumé géologique: division des terrains jurassiques en étages*' (p. 600 to end) which was published in 1850. (SEE Sherborn, 1899.) This year should, therefore, be taken as the starting point of stage and zonal momenclature; for, although some of the stage names were mentioned in earlier pages, published from 1842 onwards, they were not defined until the *Résumé* of 1850.

The stages and zones of the Jurassic and Cretaceous were recapitulated in convenient summary form, and in some cases amplified, in D'Orbigny's *Cours élémentaire de paléontologie et de géologie stratigraphiques* vol. ii, 1852, and elucidation of the paleontologic contents of the stages can often be found in the *Prodrome de paléontologie stratigraphique universelle* vols. i and ii, 1850. Before these works were published some names ending in -ien had been used adjectivally as long ago as 1829 (*e.g.*, Brongniart's "Marnes hâvriennes"). Others had been used with entirely different scope from that given them by D'Orbigny and understood ever since (*e.g.*, Brongniart's Oxfordien, 1829, covered the whole Middle Jurassic and was so used by Marcou and others before 1850; D'Omalius d'Halloy first used the term Bathonien in 1843 as synonymous with the German Dogger.) To attempt to unravel and revert to these ancient meanings would produce only chaos. Before 1850 knowledge of the formations was not sufficiently advanced for stage names of lasting value to be introduced.

For the whole Jurassic and Cretaceous, D'Orbigny used only two stage names which have to be rejected under Rule 1 (that stage names must be formed on place names)—namely, Liasien and Corallien, and both have already been discarded by almost universal consent. Liasien was long ago replaced by Pliensbachian (Oppel, 1858). Corallien, applied to a facies of the Upper Oxfordian and Kimeridgian, was also rejected by Oppel, and is unnecessary. D'Orbigny's lowest Jurassic stage, the Sinemurian, being disproportionately large, has been deprived of its lowest zones, which were separated as the Hettangian by Renevier in 1864. With these three amendments D'Orbigny's stages for the Jurassic and Cretaceous stand as follows. They represent a well-balanced scale of subdivisions and every name has been continuously in use to this day.

TERRAINS CRETACÉS	DANIAN (Denmark)
	SENONIAN (Senones, modern Sens, France)
	TURONIAN (Turonia, modern Touraine, France)
	CENOMANIAN (Cenomanum, modern Le Mans, France)
	ALBIAN (Alba, modern Aube, France)
	APTIAN (Apt, Basses-Alpes, France)
	NEOCOMIAN (Neocomum, modern Neufchatel, Switzerland)
TERRAINS JURASSIQUES	PORTLANDIAN (Portland Island, England)
	KIMMERIDGIAN (Kimeridge, Dorset, England)
	OXFORDIAN (Oxford, England)
	CALLOVIAN (Callovium, modern Kellaways, Wilts, England)
	BATHONIAN (Bath, England)
	BAJOCIAN (Bajoce, modern Bayeux, France)

TERRAINS JURASSIQUES	TOARCIAN (Toarcium, modern Thouars, France) PLIENSBACHIAN (Pliensbach, Württemberg, Oppel, 1858) SINEMURIAN (Sinemurium, modern Sémur, France) HETTANGIAN (Hettange, Lorraine, France, Renevier, 1864)

It can still be said for the Jurrassic as it was said by Toucas (1882, p. 155) for the Cretaceous, that "D'Orbigny's stages seem to fulfil all the conditions required, and they have the extra advantage of having been accepted by nearly all geologists."

SUBDIVISION OF THE STAGES

If these stages could be agreed upon as the standard, henceforth there would be no harm in the local use of other smaller stages which may be more convenient locally, so long as it is clearly understood that they represent subdivisions of a second order of rank: *e.g.*, Aalenian for the Lower Bajocian of Württemberg, Domerian for the Upper Pliensbachian of England, where it happens to coincide with the Middle Lias and so is more convenient than Pliensbachian which straddles Middle and Lower Lias. Generally, however, the division of D'Orbigny's stages into Lower, Middle, and Upper should suffice for precision in comparing known deposits or dating new ones in other continents. It seems that nothing is gained by referring to the Bedoulian and Gargasian rather than the Lower and Upper Aptian; but the substages of the Neocomian (Valanginian, Hauterivian, Barremian) are so well established in the literature that an Opinion might be rendered authorizing them to be used where suitable ammonitiferous deposits exist.

INTERPRETATION OF THE STAGES

D'Orbigny gave three classes of criteria for the recognition of each stage, stratigraphic, paleontologic, and lithologic:

(1) According to the "superposition" it is the Oxfordian stage.

(2) According to the fossils it is the Scypheenkalk, etcetera . . . , and the zone of *Ammonites cordatus*, *Plicatula tubulifera*, etcetera.

(3) According to the lithologic composition it is the Terràin a chailles etcetera.

Of these the first seldom contributes anything to the identification, and thus we are almost always left with (2) and (3) only. The troubles begin where D'Orbigny under (2), names zonal ammonites which have since been proved to occur in formations other than those he listed in (3)—in other words when his criteria under (2) and (3) are inconsistent. Before a standardized system of stages can be recommended, agreement will have to be reached as to how such inconsistencies should be reconciled. The first impulse of the "modern" is probably to be guided by paleontology and to ignore the stratigraphic data. Since the stages are founded on strata and named after places, each based on a type locality, it is more logical to define the stages by the formations rather than by the fossils. The latter were more easily subject to misidentification, and there is a separate time scale of zones based upon them.

The classic instance of ambiguity arises over the demarcation between the Portlandian and the Kimmeridgian. Before we follow Muller and discard the Portlandian stage on account of its ambiguity (a procedure in any case excluded by the rule of priority here advocated) it is well to examine the criteria given by D'Orbigny. Be-

cause he listed as fossils of the Portlandian stage *Ammonites* (now *Gravesia*) *irius*, *A. gigas*, and *A. gravesianus*, characteristic of the "Portlandkalk" of the Germans and now known to occur in the Middle Kimeridge Clay at Kimeridge, many authors restrict the Kimeridgian to equivalents of the Lower Kimeridge Clay and consider the rest Portlandian. However, D'Orbigny in founding the Portlandian stage clearly stated, "I derive this name from the Isle of Portland, England, where the first type-section has been described . . . It is the Portland Stone and Portland Sand of Fitton." Further, in founding the Kimmeridgian stage he stated, "I have derived this name from the village of Kimmeridge [Kimeridge], England, where the type-section has been described . . . It is . . . the Kimmeridge Clay and the Weymouth beds of Fitton." (D'Orbigny, 1850, p. 610) There is here no ambiguity. The *Gravesiae* were included among the Portlandian fossils purely on account of misidentification with Portland Stone ammonites, probably because of the similar matrix. It seems absurd to perpetuate the error by redefining the scope of D'Orbigny's stages to suit it—a piling up of fresh errors upon the old. Moreover, perhaps by an intuitive afterthought in which he glimpsed the truth, D'Orbigny classed the German Portlandkalk (*i.e.*, the Gigas beds) in the Kimmeridgian and not in the Portlandian.

Thus Muller's proposal to discard the Portlandian stage should be rejected emphatically. He proposes to substitute for it the term Bononian as used by Pavlow in 1896 for the Portland beds plus the Upper and Middle Kimeridge Clay, without mentioning that Pavlow's was a misuse of an earlier and almost identical term, Bolonian, differing by only one letter and founded upon the same place (*Bononia* or *Bolonia*, Boulogne-sur-Mer). The Bolonian stage was introduced by Blake (1881, p. 581)

"for the series of deposits which overlie the true Kimmeridgian or Virgulian, and underlie the true Portland Beds . . . These Bolonian beds admit of twofold subdivision . . . In the Boulogne area the two parts here distinguished have been called the 'Lower and Middle Portland'."

Thus Blake's Bolonian stage was introduced expressly to distinguish the beds from the Portlandian stage which Muller now wishes us to include under an almost identical, but later, term. Moreover, Pavlow does not seem to have deliberately changed the spelling to suit a new meaning, or even to have realized that he was misusing Blake's term. Subsequently some authors (*e.g.*, De Lapparent 1906, p. 1257) have used Pavlow's form Bononian in Blake's sense. The term is therefore highly ambiguous and covers only beds already named more than 30 years earlier.

Muller also recommend that the "Bononian", together with Pavlow's "Aquilonian" (= Purbeckian of Brongniart, 1829, *et auct.*) should rank as substages of Oppel's Tithonian stage, introduced in 1865. According to the rules here recommended, Tithonian is invalid because not formed upon a place name (Tithon was the spouse of Eos (Aurora), goddess of the dawn). Used in so many senses that it is now almost meaningless, the term Tithonian is based on the peculiar Mediterranean facies and in its original denotation has too wide a scope to be incorporated in our modern table, since it embraces most of the Kimmeridgian, the whole Portlandian, and the Purbeckian. It might be thought that the last word had been said upon this ancient controversy by De Lapparent (1906, p. 1259), who wrote in summary:

"Thus the Tithonian stage did not constitute a new member of the Jurassic system, a sort of 'post-Portlandian' stage, as some authors have understood it; rather, the name should properly be used to designate the uniform facies of a whole series of beds, which differed greatly from the contemporaneous strata deposited in the north."

It is, in fact, purely a facies term for the Tethyan deposits, spanning from the Lower Kimmeridgian to the top of the Jurassic. (*See* Haug, 1898; for further details of the Tithonian, *see* later discussion.)

Another complication is that D'Orbigny included the Purbeck beds in the Neocomian, regarding them as Cretaceous. If the rules here recommended are adhered to, however, and no new stages subsequent to D'Orbigny's are admitted, this difficulty solves itself automatically. Since the Purbeck beds are now regarded as Jurassic and have to be ejected from the lowest Cretaceous stage, they descend automatically into the highest Jurassic stage and become the Upper Portlandian. This solution was long ago arrived at by Maillard (1884, p. 144) who monographed the French Purbeck Beds, and it has been familiarized by the principal European textbooks, such as those of De Lapparent (1906, p. 1257) and Haug (1921, p. 1081). If a separate substage name is felt necessary for the Purbeck beds, which occur at intervals from Oxford to the Jura Mountains and locally exceed 500 feet in thickness, the obvious choice is the time-honored name Purbeckian, which has been in almost constant use (*e.g.*, Geikie, 1885, p. 799; Haug, 1921, p. 1081; De Loriol and Jaccard, 1865, for the French and Swiss Jura, and all subsequent monographs on that region). Before Purbeckian could be adopted as an officially recommended sub-stage, however, a suspension of the rules would be necessary, for the first post-D'Orbignyan stage name for the Purbeck beds is Dubisian, a name never since used, and deliberately passed over even by the monographers of the Purbeck Beds in the type locality of Doubs in the French Jura. (Desor, 1859, quoted in De Loriol and Jaccard, 1865; Maillard, 1884; 1886).

Muller recommends that the name Aquilonian (Pavlow in Pavlow and Lamplugh, 1892, p. 192, restricted by Pavlow, 1896) should be used instead of Purbeckian. The justification usually put forward for this name is that stage names should always be based upon a type locality where the beds are developed in marine facies. But the placing of the Aquilonian above the Portland beds, as equivalent to the Upper Tithonian, assumes correlation with the Purbeck beds, which, moreover, are partly marine even in England and have, in the Jura Mountains, yielded fragments of ammonites which H. Douvillé and Kilian considered Upper Tithonian forms (Maillard, 1886, p. 9, Pl. i, fig. 1). Pavlow himself (1896) wrote "Aquilonian (= Purbeckian)". If this assumed correlation is correct, a separate name becomes unnecessary. In any case Aquilonian is invalidated by two of the rules here advocated: (1) It is not formed on a place name (*Aquilo*, Latin, means the north wind); and (2) it is practically a synonym of Ardescian (*Ardesca* = Ardèche, France), introduced by Toucas (1890, p. 564, 570) for most of the marine Upper Tithonian in Neumayr's and Kilian's sense; *i.e.*, by Toucas' original definition the zone of *Berriasella calisto* and *B. privasensis*, or the beds below the Cretaceous (Berriasian) Boissieri zone and above the zone of *Subplanites contiguus* (Catullo) (Table 3). A further objection to Aquilonian is that it was originally introduced with much wider scope, to include the Neocomian *Polyptychites* beds which Pavlow later (1896)

realized were Cretaceous. Even as restricted (1896) it includes the Cretaceous Ryasan beds. It is almost a synonym of, and shares the shortcomings of, Mayer-Eymar's Berriasian, which was defined as embracing both the Purbeckian and the Lower Valanginian. The sooner both cease to be used the better.

Another line of demarcation that has been disputed is that between the Callovian and Oxfordian stages. Formerly, (1933) the present author maintained that the Callovian should comprise only the Kellaways beds of Kellaways, Wiltshire, and that the whole of the Oxford Clay of Oxford should be included in the Oxfordian; however, he has come to the conclusion that this would be wrong. The case is not analogous with Kimmeridgian and Portlandian, for, in spite of the implications of the names, D'Orbigny's type localities are not Kellaways and Oxford but Yorkshire. At that date too little was known of the development of the beds at either Kellaways or Oxford to enable D'Orbigny to make them type sequences. The Kimeridge Clay and Portland beds of Dorset had been elucidated and described by Fitton (1836) and by Buckland and De La Beche (1836), but the only adequately detailed authority for the Kellaways beds and Oxfordian was Phillips' *Geology of Yorkshire* (1829, 2d ed. 1835). D'Orbigny (1850, p. 608) clearly stated of the Callovian: 'It is the Kelloway-Rock, Phillips"; and of the Oxfordian: "It is . . . the Oxford Clay, the Calcareous Grit, the Coralline Oölite, Phillips, Yorkshire; the coral rag Sowerby." The south of England is not mentioned. There is, therefore, no ambiguity, for it has long been known that "Kelloway Rock" of Phillips in Yorkshire (including William Smith's better-named Hackness Rock) includes the zones up to the Lamberti zone, and that the Oxford clay on the Yorkshire coast, described by Phillips, begins with the Mariae zone. The line of division should, therefore, be drawn between the Lamberti and Mariae zones, which is where it has always been drawn in the Russian literature and much of the German, including the recent revisions by Krenkel (1915) and Brinkmann (1927 et cetera), which are the most important relevant works of the present century. In the French literature also the Lamberti zone has sometimes been placed in the Callovian (*e.g.* by Wohlgemuth, 1881, p. 276, in an important paper). D'Orbigny listed both *Ammonites lamberti* and *A. mariae* as Callovian fossils, but this is another case where the placing of a fossil is inconsistent with the clearest stratigraphic indications, in this instance not only for the type locality, but also for adjoining countries; for the Mariae zone constitutes the "Marnes oxfordiennes" of Thurmann, Gressly, Thirria, and Marcou, which were placed by D'Orbigny in the Oxfordian stage, while in Normandy nothing above the Argile de Dives(= Lamberti zone) was placed in the Callovian.

The lines of demarcation between the Bajocian and Bathonian, and between the Bathonian and Callovian stages cannot be so readily settled, for D'Orbigny's stratigraphic statements are less clear. He defined the Bajocian as not only comprising the Oölithe de Bayeux but also the Marnes de Port-en-Bessin in Normandy and the equivalent Fuller's Earth in England as well as the Inferior Oölite of Dundry ("type anglais"). The Bathonian was defined as the Great Oölite, Forest Marble, Stonesfield Slate and Cornbrash of England. It is now known, however, that the Fuller's Earth with its banks of *Ostrea acuminata* is much older in the east and south of the Paris Basin (Parkinsoni zone) than in Normandy and England, and so the inclusion

of the Anglo-Norman Fuller's Earth in the Bajocian was due to miscorrelation by lithology. In Dorset, also, limestones of the Zigzag subzone (top of the Parkinsoni zone) pass laterally into Fuller's Earth clays. In order to bring the definitions of the Bajocian and Bathonian into line with the almost universal usage of nearly a century (initiated by Oppel), it is necessary to detach from the Bajocian the bulk of the Marnes de Port en Bessin (excepting the basement beds of marly limestone a few inches thick) and place them and the bulk of the English Fuller's Earth in the Bathonian. Support for this may be derived from D'Orbigny's including some of the Fuller's Earth, which he believed to be post-Bajocian, in the Bathonian—"les marnes à *Ostrea acuminata* de Mm. Thurmann et Thiria" (D'Orbigny, 1850, p. 607)—and by his mentioning *Ostrea acuminata* as a zone fossil of the Bathonian. Nevertheless the procedure required to justify the established usage is at variance with D'Orbigny's statements regarding the type locality, Normandy, and is inconsistent with that advocated above for the settlement of the scope of the Callovian to Portlandian stages, and should be the subject of a special Opinion. An Opinion on this boundary line is very desirable in any case, since some authorities (*e.g.*, Wetzel, 1924) have gone to the other extreme and expanded the Bathonian to include the Garantiana and Niortense zones, a procedure for which there is no historical justification.

A somewhat similar difficulty, though on a smaller scale, arises over the boundary between the Bathonian and Callovian. D'Orbigny placed the Cornbrash in the Bathonian, but at that time it was not known that only the Lower Cornbrash contains *Clydoniceras discus*, one of his zone fossils for the Bathonian, while the Upper Cornbrash (to which belongs all the Cornbrash of Yorkshire) belongs to the Macrocephalus zone, which he, and practically every subsequent stratigrapher, regarded as basal Callovian. Here again the advance of knowledge has produced a conflict between D'Orbigny's stratigraphic and paleontologic criteria, but in this case it seems that the stratigraphic adjustment is so trivial, involving only a small part of the Cornbrash limestone in certain (not all) districts of England, that an Opinion ought to be promulgated to retain the Macrocephalus zone in the Callovian in accordance with ancient usage. It has been Callovian since Oppel's time, and D'Orbigny himself stated that he doubted whether the ammonites recorded as *A. macrocephalus* and *A. herveyi* from Bathonian rocks were the same species as the typical Callovian forms—a remark since fully justified, for the ammonites referred to were *Morrisiceras*, now known to be a Bathonian genus.[2]

Since the stages of the Lias are all named after French and German type localities, settlement of any adjustments that may be required in the Lias is primarily the responsibility of specialists familiar with those countries. No great divergencies from Muller's recommendations are to be expected.

OTHER CRITERIA SUGGESTED FOR INTERPRETATION OF THE STAGES

The only other criterion that has been seriously advocated for selecting and interpreting the stages is "usage" (Muller, 1941, p. 1431). Usage, however, varies from

[2] That the true *macrocephalus* and *herveyi* occur only in the Callovian was already pointed out by Hébert (1857, p. 39, 42).

country to country and from generation to generation. Who is to pronounce judgment on what usage is? Is it to be decided upon the number of papers following a particular arrangement, when it is French custom to publish perhaps four short notes on one season's work in a single quarry, and German custom to collect observations extended over many years into a weighty treatise? Or are the authors to be awarded marks according to their supposed prestige? Any scheme based upon such a foundation seems unlikely to give universal satisfaction and is bound to be subjective.

ZONES

THE PURPOSE AND LIMITATIONS OF ZONES

Arbitrary settlement of zones by priority or any other rule is not so easy, because (1) the zonal indices must be appropriate, which old species named up to 90 years ago often are not, and (2) by their nature zones are not of universal application. A stage is an artificial concept transferable to all countries and continents; but a zone is an empirical unit. If the zonal index species and its associated fauna are absent we cannot record the zone as present. Therefore, a zonal table must have specific reference to a particular area. European stratigraphers have devoted nearly a century to attempting to correlate the Jurassic deposits of the four areas—Northwestern Europe, the Jura Chain, the Alpine-Mediterranean Province, and Russia, and by no means all the difficulties have yet been solved. Both for stratigraphic work within each of these areas and as a preliminary basis for ultimate correlation between them, it has been found necessary to evolve a separate zonal table appropriate to each area. Muller recognizes the difficulties of correlating these areas but recommends a composite zonal standard "pending further research". But surely, pending attainment of these ultimate objectives, a composite zonal scheme begs all the questions and should be avoided.

If we mix the zonal tables built up in different provinces we thereby depart from the factual basis of the science and obtain a misleading, synthetic result. The so-called zonal succession shown in Muller's Table 1 does not represent any actual succession of zones anywhere and consequently is unusable in any area. If a new Upper Jurassic deposit is discovered, for instance, in the American continent, its discoverer will want to compare its ammonite fauna with actual described successions in the type areas, not with an unreal, synthetic table of zones. The affinity of his new fauna with a faunal province of Europe will be one of the most important things he wishes to establish, and to do this he must know the actual succession of zones in each of those provinces. Moreover, every new fauna so described and compared is a potential source of new light on the old problems of correlation within Europe. For general dating there are already the stages. Comparison of new faunas with zones should be with actual zones in a particular province.

In summary, zones are units of more restricted function than stages. Attempts to give them universal application are misdirected; such attempts merely make zones synonymous with subdivisions of stages and at the same time deprive them of their special qualities as the basis of correlation from one province to another.

Therefore, the rule of priority should be applied in the choice of zonal indices,

subject to two overriding provisoes: (1) the index species must be appropriate—not too long-ranged nor too rare; and (2) it must belong to the faunal province for which the zone is to be used.

THE HISTORY OF ZONAL TABLES

Zones were first introduced into geology by D'Orbigny in his works of 1850 and 1852, but only as paleontologic second names for stages. Each stage was regarded as the zone of two or more ammonite species, without any suggestion that they were successive species within the stage.

It was Oppel, in his famous book, *Die Juraformation*, (1856–1858), who first propounded a scale of zones in the modern sense—many successive zones to each stage. His table for the Lower Jurassic (Lias) and Bajocian has stood the test of time so well that it is used almost unchanged to this day (Table 1). A few blanks have been filled in here and there, and there has been much subdivision, but on the whole the table is so free from controversy that no more will be said here about the zones of the Lower Jurassic and Bajocian; especially since the zones of the Lias have been the subject of a special paper by Spath (1942), whose amendments are incorporated in Table 1.

The Bathonian Oppel (1862, p. 146, 148) provided with only one zone, that of *Oppelia aspidoides*, for the Cornbrash, and this was adopted by his pupil, Waagen, in his first work (1864, p. 91). Shortly afterwards Waagen (1869) added *Parkinsonia ferruginea* for the Lower Bathonian, apparently adopted from Schloenbach (1865, p. 29, 30). Neumayr (1871b, p. 48), on the other hand, preferred *Oppelia fusca* for the Lower Bathonian, but this index is antedated both by *Parkinsonia ferruginea*[3] and by *Procerites quercinus*, the latter introduced by Terquem and Jourdy (1869). None of these indices is appropriate for Northwestern Europe, and both oppelids were rejected by Lissajous (1923) as useless in the Mâconnais, on the south side of the Paris basin. The present author has studied the English Bathonian for 20 years and also knows that of northern France, but he is still not satisfied as to the succession of ammonite species or their vertical ranges, even within that area. The only firm zone is that of *Clydoniceras discus* for the Lower Cornbrash at the top—one of D'Orbigny's original indices (1852). With this exception, the Bathonian zones should not yet be finally crystallized.[4]

The Upper Jurassic is still more difficult to zone, for in this period the faunal provinces became strongly differentiated. As Waagen (1864, p. 98) wrote, "The higher we climb in the Jurassic series the greater become the difficulties, either of recognizing or separating individual beds, or of correlating". Oppel at first (1856–1858) provided only four zones for the Upper Jurassic: Macrocephalus, Anceps, Athleta (borrowed from D'Orbigny), and Biarmatus; but later (1862–1863) he added five more: Transversarius, Bimammatus, Tenuilobatus, "Mutabilis" (= Pseudomutabilis), and Steraspis. These, however, with only three exceptions (Macrocephalus, Athleta, "Mutabilis"), were based on southwest Germany and the neighboring countries in the Jura chain, on the margin of the Tethyan province, and are not applicable to the

[3] For difficulties in the interpretation of *P. ferruginea* see Wetzel, 1911, p. 200, and Dorn, 1927.

[4] *Macrocephalites herveyi* (*cf.* Muller, 1941, Table 2) is a fossil of the Upper Cornbrash, Macrocephalus Zone, Callovian.

TABLE 1.—*History of Jurassic ammonite zones, and standard column for Northwest Europe*

Stages	D'Orbigny 1852	Oppel 1856–1863	Other authors (see text)	Salfeld 1913–1914	Northwest Europe standard zones
					(Purbeck Beds)
PORTLANDIAN	giganteus and irius			giganteus okusensis gorei	Titanites giganteus Kerberites okusensis Glaucolithites gorei
			"scythicus" (1926)		Zaraiskites albani
KIMMERIDGIAN	lallierianus and "decipiens"		pallasioides (1924) rotunda (1924)	pallasianus	Pavlovia pallasioides Pavlovia rotunda
				pectinatus	Pectinatites pectinatus
			wheatleyensis (1924)	"miatschkoviensis"	Subplanites wheatleyensis Subplanites spp.
		steraspis	gigas (1868)	irius gravesiana	Gravesia gigas Gravesia gravesiana
		"mutabilis"	caletanus (1872) orthocera (1872)	pseudomutabilis mutabilis	Aulacostephanus pseudomutabilis Rasenia mutabilis
		tenuilobatus	cymodoce (1881)	cymodoce baylei	Rasenia cymodoce Pictonia baylei
OXFORDIAN	canaliculatus cordatus oculatus	bimammatus	achilles (1881)	pseudocordata decipiens "wartae"	Ringsteadia pseudocordata Decipia decipiens Perisphinctes cautisnigrae
		transversarius	marantianus (1881) plicatilis (1878) cordatus (1850)	antecedens martelli	Perisphinctes plicatilis Cardioceras cordatum
		biarmatus	mariae (1881)		Quenstedtoceras mariae

	lunula	biarmatus	lamberti (1860)		Quenstedtoceras lamberti

CALLOVIAN	lunula	biarmatus	lamberti (1860)		Quenstedtoceras lamberti
	athleta	athleta			Peltoceras athleta
	coronatum jason	anceps			Erymnoceras coronatum Kosmoceras jason
		macrocephalus	calloviense (1913) koenigi (1913) macrocephalus (1913)		Sigaloceras calloviense Proplanulites koenigi Macrocephalites macrocephalus
BATHONIAN	discus and bullatus	aspidoides			Clydoniceras discus
			fusca (1871) quercinus (1869) ferruginea (1869)		(Not yet determined)
BAJOCIAN	parkinsoni and polymorphus	parkinsoni humphriesianum sauzei sowerbyi murchisonae torulosus			Parkinsonia parkinsoni Stephanoceras humphriesianum Otoites sauzei Sonninia sowerbyi Ludwigia murchisonae Lioceras opalinum
TOARCIAN	bifrons and serpentinum	jurensis			Lytoceras jurense Hildoceras bifrons Harpoceras serpentinum Dactylioceras tenuicostatum
PLIENSBACHIAN	spinatus margaritatus	spinatus margaritatus davoei ibex jamesoni			Paltopleuroceras spinatum Amaltheus margaritatus Prodactylioceras davoei Tragophylloceras ibex Uptonia jamesoni
SINEMURIAN	bisulcatus and catenatus	raricostatus oxynotus obtusus			Echioceras raricostatum Oxynoticeras oxynotum Asteroceras obtusum
		bucklandi			Arietites turneri Arnioceras semicostatum Coroniceras bucklandi
HETTANGIAN		angulatus planorbis			Scamnoceras angulatum Psiloceras planorbis

northwest European province, in which are the type localities of all D'Orbigny's Middle and Upper Jurassic stage names.

THE UPPER JURASSIC OF THE NORTHWEST EUROPEAN PROVINCE

The first comprehensive zonal scheme for the Upper Jurassic of northwest Europe, omitting the Callovian and Lower Oxfordian, was propounded by Salfeld (1913; 1914). Notwithstanding some errors of stratigraphy and correlation, later corrected by Chatwin and Pringle (1922), Neaverson (1924), and others, Salfeld's table provides a firm framework for the highest stages of the Jurassic of this region, comparable with Oppel's table for the Lias and Bajocian. In the Standard Sequence given in the right-hand column of Table 1, Salfeld's indices are retained wherever possible. (*See* the column alongside.) The exceptions are as follows, from the top downwards:

Salfeld's Pallasianus zone was in several respects inadequate. The Portlandian part may equate with the Scythicus zone in Poland and Russia, but the index fossil identified on the Dorset coast has had to be renamed (*Zaraiskites albani*[5] Arkell sp., 1935, p. 334, 339), and it is advisable to retain this separate zonal index for northwest Europe pending further investigation. The Kimmeridgian part of Salfeld's Pallasianus zone (340 feet thick on the Dorset coast) has been subdivided by Neaverson (1924).

Salfeld's Miatschkoviensis zone was based on misidentification of *Subplanites* spp. with Russian forms which are certainly later. *P. miatschkoviensis* Vischniakoff is a *Dorsoplanites*, a genus only doubtfully represented outside the boreal province in the English Pallasioides zone (Hartwell Clay).

Salfeld's Irius zone has been shown by Roll (1932) to be the same as the ancient Gigas Zone of both northwest and southwest Germany and the Paris basin, which was so called as long ago as 1868 in France (De Loriol and Cotteau, 1868) and was known as the Gigas beds in Germany at least since 1864. (*See* Schloenbach, 1865, p. 44.) The old name should take priority, although in France the fossil, so-called, was generally that later renamed *Gravesia portlandica* (De Loriol) (a particularly unfortunate specific name). The first recognition of two *Gravesia* horizons, with "Irius beds" at the top, was made in the Haute Marne (De Loriol, Royer and Tombeck, 1872).

Salfeld subdivided Oppel's "Mutabilis" (= Pseudomutabilis) zone (Oppel, 1863, p. 252), but it is doubtful whether *A. yo* is of chronological value. So far no sucession within the *Aulacostephanus* beds has been established, although they exceed 300 feet in thickness in Dorset, where they are almost the same, lithologically and paleontologically, as on the Lower Volga (Pavlow, 1886). Careful collecting of the crushed impressions may one day prove fruitful, however. Fortunately Oppel's index species, *A. pseudomutabilis* (De Loriol), although first applied to the Swiss Jura, is highly appropriate. He later (1865b) used *A. eudoxus* (D'Orbigny) in the Ardèche. Both species antedate *Aspidoceras caletanum* (Oppel), used by De Loriol, Royer, and Tombeck (1872). Like *A. lallierianum*, D Orbigny's (1852) index, and *A. acanthi-*

[5] *Provirgatites* Lewinski, 1923, is said to be a synonym of *Zaraiskites* Semenow (Spath, 1936, p. 29), but I have not been able to obtain Semenow's paper.

cum, all these numerous species of *Aspidoceras* seem to have long ranges, besides being difficult to identity. For this reason, too, De Loriol, Royer and Tombeck's zone of *Aspidoceras orthocera* (D'Orbigny), also founded for the Haute Marne and used by Hébert (1873) at La Rochelle, should not be retained merely on account of priority. As first used by De Loriol, Royer and Tombeck (1872), it embraced everything from the Pictonia zone to part of the Pseudomutabilis zone, and it was adopted by Hébert (1873) and Douvillé (1881) for other parts of the Paris Basin only in a restricted sense, for which Salfeld's index, *Rasenia mutabilis* (Sowerby, *not* D'Orbigny), is much preferable.

Hébert (1873) recognized Cymodoce beds at La Rochelle, and Douvillé (1881) used a Cymodoce zone in his table of the zones of the Paris Basin. It may eventually be found expedient and more in scale with the northwestern European zonal scheme, as a whole, to retain this zone with three subzones: the true Cymodoce subzone in the middle, Salfeld's zone of *Pictonia baylei* at the base, and a third subzone of *Rasenia uralensis* (D'Orbigny) at the top.

For the uppermost Oxfordian there is still a similar lack of finality in our knowledge, and it is too early to attempt to standardize zonal indices. De Loriol, Royer and Tombeck (1872) in the Haute Marne recognized two zones above the Plicatilis zone, which they referred to as the Achilles beds (above) and the Marantianus zone (below). Hébert (1873) identified the same sequence on the Atlantic coast at La Rochelle. Douvillé (1881) adopted both ammonites as zonal indices for the Paris Basin. Salfeld (1913) subdivided the Achilles zone into his zones of *Ringsteadia pseudocordata* above and *Decipia decipiens* below, adding *Decipia achilles* as alternative index to the Decipiens zone, although he recognized that De Loriol, Royer and Tombeck (1872, p. 64, Pl. iv, fig. 2) had figured *Ringsteadia frequens* Salfeld from their Achilles beds (sub *Ammonites schilli*). *Ammonites achilles* D'Orbigny is not a very satisfactory index at present, as no types are to be found[6], but at least as used by De Loriol and others it belongs to the genus *Decipia*. Here again it may be decided eventually to retain the Achilles zone and recognize Salfeld's Decipiens and Pseudocordata zones as subzones, perhaps with a third Variocostatus subzone between them.

Ochetoceras marantianum (D'Orbigny), used as zonal index by De Loriol, Royer and Tombeck (1872) and by Douvillé (1881), was first tentatively proposed by Oppel (1862, p. 159) for southwest Germany, but dropped the next year and incorporated in his Bimammatus zone (Oppel, 1863, p. 165). This oppelid is quite unsuitable for the northwestern European province, in which it probably does not occur. The equivalent beds contain no *Ochetoceras* in Britain or northwestern Germany or the adjoining parts of France. Salfeld's new index, *Perisphinctes wartae* Bukowski, (Salfeld, 1913, p. 429) however, was misidentified and has had to be renamed (*P. cautisnigrae* Arkell 1935–1945, p. 57, pl. xiii). Salfeld's alternative index, *Amoeboceras alternans* (Von Buch), is as unsuitable as *O. marantianum*, for the same reasons, and is preoccupied for quite different beds in Russia (Nikitin, 1884; *see* Rosanov, 1918).

The Plicatilis zone was so named at least as early as 1878 (Hudleston), and this index has been used by the British Geological Survey almost ever since (Woodward, 1895); and in France the equivalent zone was known long before as the Plicatilis lime-

[6] Before the war Dr. J. Cottreau kindly searched for types on the author's behalf in Paris, but without success.

stone or Plicatilis beds (*e.g.*, by Hébert, 1857, p. 55). It includes the Antecedens and Martelli zones of Salfeld's tables (1913; 1914). While *Perisphinctes antecedens* Salfeld may possibly be used as a subzonal index for the upper part of the zone, *P. martelli* (Oppel) (= *P. plicatilis* D'Orbigny in part, not Sowerby) has not been found in the northwestern province. (*See* Arkell, 1935–1945, p. 70, 101; 1936, p. 150–151.)

This and the remaining zones of the Oxfordian and Callovian have been discussed in detail elsewhere (Arkell, 1936; 1939; 1941). In every case the column on the right in Table 1 embodies the earliest valid and appropriate index known to the writer for each zone. Four of them are from D'Orbigny. The date at which each is believed to have been first proposed as a zonal index will be found in the third column from the right. *Quenstedtoceras lamberti* (Sowerby) seems to have been first used as a zonal index by Hébert (1860), and *Q. mariae* (D'Orbigny) by Douvillé (1881), though Hébert (1857, p. 44) wrote of a Lamberti and Athleta bed. Lamberti and Cordatus were already adopted for Switzerland, and the Ardèche by Oppel (1865b) and also Jason and "Ornatum" for Southwest Germany by Neumayr (1871, p. 520). The indices for the necessary subdivisions of Oppel's Macrocephalus and Anceps zones are taken partly from D'Orbigny (1852) and partly from Buckman (1913). *Reineckeia anceps* cannot be used as a zonal index in Northwestern Europe because not only this species but all reineckeids are extremely rare, and the very few specimens that have been found are distributed between the Koenigi and Lamberti zones inclusive.

THE UPPER JURASSIC OF THE JURA CHAIN (BAVARIA-SWITZERLAND-FRANCE)

In the left-hand column of Table 2 are shown the zones proposed by Oppel for the Upper Jurassic of this province. The highest five were first published in 1862–1863 (p. 159, 163, 165, 173, 175, 252). Oppel had planned, and partly completed in manuscript, an exhaustive study of the Upper Jurassic rocks when his work was cut short by early death. Only a small part, dealing with the zone of *Ammonites transversarius*, was published posthumously, under the editorship of Waagen (Oppel, 1866). To judge by this fragment, Oppel himself did not intend his new zones to apply to the Northwestern European province, for he made no reference to that region in this connection, although he dealt exhaustively with most of the parts then known of the Tethyan province. Muller's recommendation (1941, Pl. 1), therefore, that we should now use, not even Oppel's historic zonal scheme, but a doctored version of it, for all areas, is unacceptable.

Moreover it will be seen from Table 2 (herewith) that this region is unsuitable to provide a universal zonal standard of the Upper Jurassic, for two reasons. In the first place, the Upper Callovian and Lower Oxfordian stages are so condensed that several zones, each embracing several subzones in Northwest Europe, are either wanting or their faunas are sparsely represented and more or less mingled, so that Oppel at first confused the Lamberti, Mariae, and Cordatus zones under his Biarmatus zone. Secondly, the Southwest German stratal record is very incomplete in the upper part. Whether the Ciliata zone represents the Upper Portlandian ("Aquilonian"), as believed by Schneid (1915) and Muller (1941), or the Lower Portlandian as believed by Spath (1933, p. 851), or some part of the Upper Kimmeridgian ("Bolonian") as believed by Roll (1932), much must be missing.

Most of Oppel's zones have been found too broad for detailed work even in Southwest Germany and other parts of the Jura chain. For Switzerland (Aargau) Oppel himself (1863, p. 163) adopted the zones of Anceps, Athleta, Lamberti (from Hébert, 1860), Cordatus (from D'Orbigny, 1852; Hébert, 1860) and Perarmatus. For Southwest Germany Neumayr (1871b, p. 520) tabulated the zones of Macrocephalus, Jason (from D'Orbigny, 1852), Ornatum, Lamberti, and Cordatus. In Table 2 are shown the working zones now used in Southwest Germany, compiled from Reuter (1927), Schneid (1914; 1915), Beurlen (1927), and Roll (1932; 1933), with the probable correlation with Northwest Europe in the column on the right.

These "working zones" for the Jura chain seem to be just as important as Salfeld's zones in Northwest Europe, though, in order to keep them in scale with the zones of the Lower Jurassic and Bajocian, they would have to be regarded as subzones of Oppel's original zones as shown in the left-hand column of Table 2. This consideration in turn points to Salfeld's zones of the Upper Jurassic being out of scale with Oppel's for the Lower Jurassic and Bajocian, and it might be advocated that the Northwest European Upper Jurassic zones should be regrouped as subzones of fewer, broader zones to balance Oppel's. Such a move in the interests of uniformity, however, would be a retrograde step, for the broader zones would be of correspondingly less use—in fact, too vague to be of any real value.

THE UPPER JURASSIC OF THE ALPINE-MEDITERRANEAN (TETHYAN) PROVINCE

In this province the divergences towards the top of the Jurassic become still more marked. The Callovian and, especially, the Oxfordian at least locally admit of detailed correlation with Northwestern Europe, by way of the Rhone Valley, rather than with Bavaria. Thus at La Voulte in the Rhone Valley south of Lyons there is typical Upper Oxford clay with pyritized ammonites showing a succession of Lamberti, Mariae, Praecordatum, and perhaps Cordatum zones, as in Southern England, although mixed with many Phyllocerates (Sayn and Roman, 1928–1930). It is significant that Oppel (1865b), in his pioneer study of this area, used the Lamberti and Cordatus zones, borrowed from D'Orbigny and Hébert in the Northwest Province, rather than his own Biarmatum zone based on Southwest Germany. Still more remarkable, at Cetechowitz in Moravia, the isolated occurrence of so-called Cordatus beds in one of the Pennine klippes (Neumayr, 1870; Neumann, 1907) contains a fauna of perisphinctids and cardiocerates almost identical with those in the lower part of the Plicatilis zone (Berkshire oölites) near Oxford, including the zonal index fossil.

Above the Oxfordian, however, the succession begins to show more marked signs of differentiation. Instead of the Kimeridge clay there follow the massive, white, pink, or blue limestones which have puzzled generations of stratigraphers. Up to the Pseudomutabilis zone inclusive, the ammonite faunas are not so different but that correlation with the Bavarian and thence with the Northwest European provinces can be established with certainty, even in such enormous limestone masses as the Mountain of Crussol (Riche and Roman, 1921) (Table 3).[7] But higher up the am-

[7] The writer had the privilege of seeing the classic sections at La Voulte and Crussol and made small representative collections, under the guidance of the late Prof. F. Roman in 1936.

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TABLE 2.—*Upper Jurassic of Southwest Germany*

(Based mainly on L. Reuter, 1927; K. Beurlen, 1927; T. Schneid, 1914; 1915; A. Roll, 1932; 1933; L. Wegele, 1929).

	Oppel's zones	Modern zones		Strata	Correlation (Northwest Europe)
?		Berriasella ciliata and Anavirgatites palmatus	ZETA	Neuburger Schichten	? pectinatus
		Subplanites vimineus		Reisberg-Schichten	Subplanites spp.
KIMMERIDGIAN	Streblites steraspis	Lithacoceras ulmensis (obere Ulmensis—Schichten)			gigas
		Taramelliceras lithographicum		Solnhofer Plattenkalk	gravesiana
		Lithacoceras siliceus	EPSILON	'Beckeri Zone' Frankendolomit and plumper Felsenkalk	(? wanting)
		Subplanites setatus			
		Sutneria subeumela			
	Aulacostephanus pseudomutabilis ("mutabilis")	Aulacostephanus pseudomutabilis	DELTA	Treuchtlinger Marmor and Schwammkalk	pseudomutabilis
	Streblites tenuilobatus	Streblites tenuilobatus and Glochiceras dentatus	GAMMA	Oberer grauer Mergelkalk	mutabilis
		Ataxioceras lothari and A. polyplocus			cymodoce
		Sutneria platynota			? baylei

OXFORDIAN	Peltoceras bimammatum (bicristatum)	Idoceras planula and Ringsteadia brandesi	BETA	Werkkalk	pesudocordata
		Peltoceras bimammatum and Perisphinctes tiziani			? decipiens ? cautisnigrae
	Peltoceras transversarium	Amoeboceras alternans	ALPHA	Impressa Mergel, Unterer grauer Mergelkalk	(? wanting)
		Peltoceras transversarium		Glauconit-Bank, Mergelkalkbänke	plicatilis
CALLOVIAN	Aspidoceras biarmatum	Aspidoceras biarmatum	ZETA	Knollenschicht and Grenztone	lamberti-cordatus
	Peltoceras athleta	Kosmoceras spinosum ('ornatum')		Ornatenton	athleta
	Reineckeia anceps	K. castor and K. pollux			coronatum
		Kosmoceras jason			jason
	Macrocephalites macrocephalus	Macrocephalites macrocephalus	EPSILON	Macrocephalen-Schicht	calloviense-macrocephalus

ZONES

TABLE 3.—*Post-Oxfordian Jurassic of the Alpine-Mediterranean province*

Strata				Crussol	Neumayr's zones	Other indices	Correlation (Bavaria)
TITHONIAN (Oppel, 1865)	TITHONIAN (Neumayr 1871–1873, Kilian, Haug)	ARDESCIAN (Toucas)	Stramberg Limestone; Upper Tithonian of Kilian; Calcaires à T. janitor		Virgatosphinctes transitorius (1871)	Berriasella calisto (Kilian, 1887) Berriasella privasensis (Kilian, 1895)	(? wanting)
			Rogoznik Beds; Lower Tithonian of Kilian, Toucas; Diphyen-kalke		Streblites semiformis (1871)	Lithacoceras geron (Kilian 1887) Subplanites contiguus (Toucas, 1890)	? ciliata ? vimineus ? ulmensis lithographicum
				Pink summit limestone			
	KIMMERIDGIEN (Auct.)		Acanthicus Beds	Calcaires du Château	Waagenia beckeri (1873)	Phylloceras loryi and Aspidoceras acanthicum (Kilian, 1895)	siliceus setatus subeumela
							pseudomutabilis
	SEQUANIEN (Kilian)			Carrière Mallet	Phylloceras isotypum (1873)	Ataxioceras polyplocus (Hébert, 1869)	tenuilobatus
				Limestones of Ravin d'Enfer			polyplocus platynota

monite fauna begins to diverge as much as the lithology, and all correlation becomes only tentative. Nevertheless, these higher zones are particularly important, because here only (unless also in Russia; *see* below) is there a continuous marine succession from the Jurassic into the Cretaceous.

Accordingly, the post-Oxfordian part only of the Upper Jurassic is shown in Table 3. The problems center inevitably around the Tithonian stage; whether we agree with Hébert that the introduction of this stage into geology has been a source of nothing but confusion, or with Neumayr, that it was a master stroke, it is essential to know what the various protagonists meant by the term, and this is indicated at the left-hand side of Table 3.

Oppel, in introducing the Tithonian (1865a, p. 535–536), defined it clearly as covering everything between the Eudoxus zone (= Pseudomutabilis zone) and the lowest Neocomian, and he envisaged its probable equivalence with the Solenhofen Schiefer, Portland limestone, and Purbeck beds.

Neumayr, on the other hand (1871b; 1873, p. 228), restricted the Tithonian to the beds above his Beckeri zone, which includes several subzones higher than the Pseudomutabilis zone (*see* Table 3), and he was followed by Toucas and Kilian in all their work on the classic areas in the Ardèche and Basses-Alpes, and by Haug (1898). It is, therefore, in this restricted sense that the term Tithonian is most commonly used in the literature, and it is still useful as a *local* stage or group name to serve the purpose for which Oppel intended it--to obviate prejudging correlations that are still open[8].

A great boon to future investigators of the still fascinating problems of this region, which the introduction of a priority rule would bestow, would be the stabilization of a series of zones for the whole area. At present there is no consistency in the use of zonal indices. Apparently zones were first proposed for the Tithonian by Neumayr (1871b, Jurastudien V, p. 516–517) who suggested *Virgatosphinctes transitorius* (Oppel) for the Upper division and *Streblites semiformis* (Oppel) for the Lower or 'Rogozniker Niveau'. (At the same time he withdrew, on the grounds of inappropriateness, *Aspidoceras cyclotum*, an index previously suggested by him.) Whether *Streblites semiformis* can be justified on other grounds than priority remains to be demonstrated. If not, the next prior index is (?) *Lithacoceras geron* (Zittel), introduced by Kilian (1887). *Virgatosphinctes transitorius*, on the other hand, was acclaimed and accepted as index by Hébert (1878, p. 111) and is recorded ubiquitously from the Upper Tithonian, by Toucas, Kilian, and other authors, although they introduced other indices. It offers a happy alternative to these other indices, *Berriasella calisto* (D'Orbigny) and *B. privasensis* (Pictet), which have been used haphazardly in the past and have both been alleged to be zone breakers. (*See* e.g. Kilian, 1887, p. 152; 1889, p. 598; 1895, pl. xi; Haug, 1898.) Both have recently been declared unsuitable, while the two subzones of *Delphinensis* and *Chaperi*, recommended in Muller's (1941) Table 1, now appear to be not only worthless but upside-down (Mazenot, 1939, p. 263). The generic attribution of *A. transitorius* Oppel here

[8] The author agrees with Muller that there is no justification for still further restricting the Tithonian to Neumayr's Upper Tithonian, a unit already covered for the most part by the term Ardescian (Toucas, 1890).

suggested, as also of *A. geron* Zittel and *A. contiguus* Catullo, is liable to revision when these groups are monographed.[9]

For the Acanthicus Beds below the Tithonian two zones have been found to suffice. The lower has always been recognized to be equivalent to Oppel's Tenuilobatus Zone, and this index might, with advantage, be adopted in order to bring out the correlation with the Jura Chain, although first Hébert (1869, p. 590) and then Neumayr (1873, p. 221) sought to improve upon it by adopting fresh indices (*Ataxioceras polyplocus* Reinecke sp. was preferred by Hébert, *Phylloceras isotypum* Benecke by Neumayr.)

For the remaining Acanthicus beds, Neumayr (1873, p. 220) introduced the zone of *Waagenia beckeri* Neumayr, defining it as the beds between the Tenuilobatus zone and the Lower Tithonian in his restricted sense—*i.e.*, below the Lithographicum zone of Bavaria and including equivalents of the Pseudomutabilis zone and a large part of Oppel's Steraspis zone. Kilian's (1895, Pl. xi) zone of *Phylloceras loryi* and *Aspidoceras acanthicum* seems to be synonymous with the Beckeri zone. The uselessness of *A. acanthicum* as a zonal index had been demonstrated by Neumayr (1873) and by Pavlow (1886).

The highest zone at which correlation between the Tithonian and other areas can be claimed as firmly established is the Lithographicum zone. *Taramelliceras lithographicum* (Oppel), the characteristic zonal index of the Solenhofen Plattenkalk in Bavaria, was recorded from various places in the Lower Tithonian by Neumayr (1873, p. 229–230), who fully appreciated its significance for correlation, and it also occurs in the pink summit limestone at Crussol (Toucas, 1889, p. 741). So useful and widespread is this index, in fact, that there seem good reasons for following Haug (1898) in promoting it to a separate zone, equal in importance to the Tithonian zones of *Semiformis* (or *Geron*) and *Transitorius*. It has been given equal status with the Pseudomutabilis zone by Kilian and Guébhard (1905, p. 824) and by Schneid (1915, p. 108).

Above the Lithographicum zone, correlations between the Alpine-Mediterranean province and other provinces are fraught with many difficulties. Although prolific ammonite faunas have been figured from the higher beds in Franconia, at Stramberg, and elsewhere, there is little exact correspondence between the several provinces, and there is much to be said for the old idea of geographical isolation (*See* Mazenot, 1939, p. 271), sometimes scorned by adherents to the dogma of "dissimilar faunas". The most promising line for correlation so far discernible is probably the assemblage of giant ammonites which occurs in the Pectinatus zone at the base of the Upper Kimeridge clay of England and in the "Bolonian" of France. Ammonites apparently more or less contemporaneous with these have been figured from Stramberg and an exotic block at Teschen (*Ammonites seorsus* Oppel, *in* Zittel, 1868, Pl. xxiv, figs. 1, 2), from the Tithonian klippe at Niederfellabrunn near Vienna (*Pseudovirgatites scruposus* Oppel sp.; Vetters, 1905, Pls. xxi, xxii), and from the Ciliata zone in Franconia (*Perisphinctes caesposus* Schneid, 1915, Pl. xii, fig. 4). Among a large collection of giant ammonites collected from the Pectinatus zone near Oxford the writer has detected none identical with Vetters' figures of *P. scruposus* (Oppel), but the Austrian species differs no more from some of the Oxford specimens than they do from one another,

[9] Uhlig, author of both genera, assigned *A. contiguus* Catullo to *Virgatosphinctes* and *A. transitorius* Zittel to *Aulacosphinctes*, but subsequent restriction and designation of lectotypes have materially altered the position.

and there is a striking general similarity. On the basis of this collection the conclusion can hardly be resisted (contrary to the opinion of Spath, 1933, p. 845) that the Niederfellabrunn *Pseudovirgatites* beds are at least approximately contemporary with the Pectinatus zone. Further, if, as Spath maintains, Buckman's English genera *Wheatleyites* and *Keratinites* are to be regarded as subgenera of *Pectinatites*, then *Pectinatites* itself (Buckman, 1922) should be separated only subgenerically from *Pseudovirgatites* (Vetters, 1905). Such differences may have a purely geographical basis, due to partal isolation or merely to great distance, which makes the time of dispersal important in relation to the rate of evolution. (*See* Arkell, 1935–1945, p. 125, 133, 141.) (A roundabout connection between two seas due to encroaching land barriers would have the same effect as great distance.)

The berriasellids of the Franconian Ciliata zone are regarded by Mazenot (1935; 1939) as earlier mutations (in the sense of Waagen, not De Vries) of the species in the Transitorius zone of Southeastern France, and he dates them to the upper part of the Geron zone (Table 3). This seems more likely than that they should be older than the Pectinatus zone as believed by Roll (1932, p. 195), although, as already remarked, some elements of the Pectinatus zone seem to be represented in the Ciliata zone.[10]

These matters of correlation are here treated in some detail because the tables of zones recommended in Muller's paper might mislead those unfamiliar with the literature or the European faunas into thinking that the problems are much more nearly settled than they really are.

THE UPPER JURASSIC OF CENTRAL RUSSIA ("BOREAL PROVINCE")

In this province, as in the last, there is tolerable certainty in the correlations with Northwest Europe up to the Pseudomutabilis zone inclusive, after which, as in the Alpine province, an altogether peculiar set of faunas makes its appearance, and these are as difficult to correlate with any others as are those of the Tithonian. For these highest Jurassic beds of the "boreal" province, between the Pseudomutabilis zone and the base of the Cretaceous, Nikitin in 1881 introduced the term Volga formation, which he and others later changed to Volgian.[11] Thus the Volgian is by definition the precise equivalent of the Tithonian in stratigraphical position, although the faunas of the two have little in common. The extreme individuality of the uppermost Jurassic rocks in the two regions demands separate terms by which to refer to them as a whole, and in this strictly local sense, for which their authors originally introduced them, both Tithonian and Volgian will always serve a useful purpose. The crucial problems arise from how to correlate the Tithonian and Volgian with one another and with the type region of the D'Orbignyan stages in Northwest Europe.

In Table 4 the classic zones of the Russian literature are shown in the left-hand

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[10] Some English *Pectinatites* also approach closely to the rather more compressed group of *P. penicillatus* Schneid (1915, pl. ii, fig. 3), also in the Franconian Ciliata Zone (genotype of *Sublithacoceras* Spath, 1925). *Cf.* also *Pectinatites aulacophorus* Buckman (1923, Pl. CCCLXXXI) and *Ammonites senex* Oppel (in Zittel, 1868, Pl. XXIII, fig. 1) from Stramberg—but not necessarily from the Stramberg beds proper (Transitorius zone).

[11] Nikitin (1881, p. 36) defined the Volga formation as "the whole mass of the Jurassic beds that overlie the Oxford Clay in Central Russia", but he included the Alternans zone in the Oxford clay (Table 4), and his Alternans zone probably included (locally) Pseudomutabilis beds; the latter were apparently first separated as a distinct zone in Russia by Pavlow (1889).

column, with their authors and the dates when they were first used as zones. In his earlier works Nikitin (1881; 1882) referred to his zones as "stages", so that their in-

TABLE 4.—*Upper Jurassic of Central Russia*

(Based on Nikitin, 1881; 1882; 1884; Pavlow, 1886; 1889; 1907; Lahusen, 1883; Ilovaisky, 1904; Borissjak, 1908; Rosanov, 1906; 1918; 1923).

Double lines indicate gaps in the sequence.

Russian zones		Russian fauna	Correlation (North-west Europe)
Craspedites nodiger (Nikitin, 1884)	UPPER VOLGIAN	Craspedites nodiger, subclypeiformis, triptychus, okensis, unshensis, catenulatus, kachpuricus, Kochina schurovskii, etc.	
Craspedites subditus (Nikitin, 1884)		Craspedites subditus, okensis, catenulatus	? Purbeckian
Craspedites fulgens (Nikitin, 1884)		Craspedites fulgens, subfulgens, okensis, subditoides, fragilis	
Titanites blakei (Pavlow, 1889)	LOWER VOLGIAN	Titanites blakei (Pavlow), Kerberites portlandensis (Cox) and giants *cf.* gigas (Moscow district). "Epivirgatites" nikitini (Simbirsk district)	giganteus okusensis gorei
Virgatites virgatus (Nikitin, 1884)		Virgatites virgatus, V. pilicensis, et al. Acuticostites acuticostatus	(wanting)
Zaraiskites scythicus (Rosanov, 1906)		Zaraiskites zaraiskensis, Z. quenstedti, Z. scythicus	albani
Dorsoplanites dorsoplanus (Pavlow, 1907)		Dorsoplanites dorsoplanus, D. panderi, etc. (Pavlovia pallasi d'Orb. sp. here?)	pallasioides
		Bituminous shale at Kachpur with Subplanites cf. schlosseri (Schneid) (J. F. Blake *in* Spath, 1923, p. 307)	Subplanites spp
Aulacostephanus pseudomutabilis and eudoxus (Pavlow, 1889)		Aulacostephanus pseudomutabilis, eudoxus, subeudoxus, undorae, subundorae, syrti, kirghisensis, Amoeboceras subtilicostatum, A. jasikowi, Aspidoceras spp., Streblites spp.	pseudomutabilis
		Rasenia fraasiforme, Prorasenia mniovnikense, P. cf. stephanoides, Amoeboceras spp.	cymodoce baylei
Amoeboceras alternans (Nikitin, 1884)	D4	Amoeboceras leucum Spath, A. ilovaiskyi Arkell (Ilovaisky, pl. xi, fig. 2, 7)	pseudocordata
	D1 C	Amoeboceras pseudocaelatum Spath (Ilovaisky, pl. xi, fig. 6; pl. x, fig. 30)	decipiens

TABLE 4.—*Continued*

Russian zones		Russian fauna	Correlation (Northwest Europe)
		Amoeboceras alternoides (Nikitin)	cautisnigrae
Cardioceras cordatum (Nikitin, 1884)	B	Cardioceras zenaidae, zieteni, densiplicatum, vagum, expositum (Ilovaisky, pl. xi, fig. 5), Periphinctes ss., Kranaosphinctes, Ochetoceres canaliculatum	plicatilis
	A2	Cardioceras zenaidae, zieteni, tenuicostatum, Aspidoceras cf. paucituberculatum Arkell	
	A1	Cardioceras cordatum, C. costicardia (Lahusen, pl. v, figs. 5, 3), C. ilovaiskyi Maire (Ilovaisky, pl. x, fig. 28), Goliathiceras rouillieri, Grossouvria	cordatus
	K	Quenstedtoceras pavlowi et al. (Ilovaisky, pl. x, figs. 22–25), Card. lahuseni Maire, etc.	mariae
Quenstedtoceras leachi (Nikitin, 1881–4)	Ilovaisky's Beds Near Moscow (1904) ↑	Quenstedtoceras leachi, Q. lamberti, et al., Eboraciceras (Nikitin, 1881, pl. i, fig. 6), Prorsiceras (pl. i, fig. 5), Pachyceras mologae, Kosmoceras spinosum, K. aff. proniae	lamberti
—		Peltoceras athleta, P. athletoides (Lahusen, 1883, pl. x, figs. 5–9); in Donetz, the Peltoceras beds of Berjesowi Ravine, Protopopowka (Borissjak)	athleta
Cadoceras milaschevici (Nikitin, 1884)		Erymnoceras coronatum, Kosmoceras castor, K. jason or obductum, K. aff. gulielmi, Cadoceras tchefkini, C. milaschevici	coronatum jason calloviense
Cadoceras elatmae (Nikitin, 1884)		Macrocephalites, Gowericeras, Galilaeiceras, Chamoussetia	koenigi macrocephalus

troduction as zones strictly dates only from 1884. (Nikitin, 1884, p. 73). In the middle column are listed some important ammonites figured by the Russian authors and now given what are believed to be their correct names. In the right-hand column are the present author's correlations, based upon his identifications of the Russian figures quoted in the middle column. At the left side of the middle column are shown Ilovaisky's beds, from his important paper (1904) on the exposures at Novoselki and Miatshkovo near Moscow, subdividing Nikitin's Cordatus and Alternans zones.

Up to the Pseudomutabilis zone, correlation is nearly complete, and there would seem to be no reason why the Northwestern European zones should not be used as the standard for Russia. The old Russian zones are nearly all much too crude to be adopted in other regions even where they may have priority (which, however, could only be claimed for the two zones of *Cadoceras elatmae* and *Amoeboceras alternans*; and,

as Rosanov (1918) has shown, the latter embraces both Upper Oxfordian and Lower Kimeridgian strata (Table 4). Rosanov pointed out that the zones on the Oxfordian-Kimmeridgian boundary are more fully represented in Russia than Salfeld supposed, but it still seems that the Mutabilis zone is missing (Salfeld, 1914, p. 238).

Above the Pseudomutabilis zone the only representative of the thick and important series of zones which make up the bulk of the Kimeridge clay in the Dorset coast sections would appear to be the bituminous shales locally developed at Kachpur (Government of Simbirsk) from which J. F. Blake collected a specimen identified by Spath (1923, p. 307) as *Subplanites* cf. *schlosseri* (Schneid). Elsewhere there seems to be a gap embracing the Gravesia, Subplanites, and Pectinatites (and Rotunda ?) zones. These, formerly lumped together as the Bleicheri zone (Haug, 1898[12]), where recognized as absent from Central Russia by Pavlow (1892, p. 201) and Rosanov (1912, quoted in Sokolov and Bodylevsky, 1931, p. 25). This is a gap much greater even than that postulated by Roll (1932) for Northwestern Europe to account for the absence of the Bavarian Subeumela, Setatus, and probably Siliceus zones (Bavarian Beckeri zone).

The classification of the Volgian has been carried out in considerably more detail; the Russians have introduced seven or eight zones for it as compared with six for all the rest of the Upper Jurassic. These zones are shown in the left-hand column of Table 4.

DORSOPLANUS ZONE: (Pavlow, 1907) Generally this zone, characteried by *Dorsoplanites*, follows immediately on the Pseudomutabilis zone or lower horizons. A measure of the disconformity is indicated by the fact that in England (Spath, 1936, p. 76) the only possible representatives of *Dorsoplanites* occur in the lower part of the Pallasioides zone (Hartwell clay) (*"Pallasiceras" ultimum* Neaverson, 1925, p. 20, Pl. i, fig. 11). In his folding table, Pavlow (1907, facing p. 84) called this the zone of *Perisphinctes boidini*, a Boulonnais species which he had previously figured from the Blakei zone (1889, Pl. iii, fig. 12), but in both cases it was almost certainly misidentified. (*See* Michalski, 1890, p. 232.) *In his text* Pavlow (1907, p. 43, 74) used *Dorsoplanites dorsoplanus* as zonal index.

Another valuable datum for correlation would be provided if it could be established at precisely what horizon in the Russian sequence the *Pavlovia* occurs which was figured by Michalski (1890, Pl. ix, fig. 4) as *Olcostephanus pallasi* (D'Orbigny). Some specimens of *Pavlovia hartwellense* (Neaverson, 1925, p. 28, Pl. ii, fig. 4) from the Pallasioides zone of Hartwell, England, are indistinguishable specifically from Michalski's figure.

SCYTHICUS ZONE: (Rosanov, 1906) This is the Quenstedti zone of Pavlow (1907, Table facing p. 84), but Rosanov's index apparently takes priority (Rosanov, 1906; 1912; 1923). Rosanov and also Sokolov and Bodylevsky (1931, p. 25) equate this zone with the Dorsoplanus zone, but both the sequence in England and the occurrence of the Scythicus zone in Poland without *Dorsoplanites* (Lewinski, 1923) support Pavlow's contention that they are two distinct zones. On the Dorset coast, forms hardly distinguishable from *Zaraiskites scythicus* (Michalski) occur in the Emmit Hill marls (Lower Portland Beds) well above the Pallasioides zone (Buckman, 1926, Pl. cvlxxv;

[12] *Subplanites bleicheri* (De Loriol), from the Gravesia zone of Boulogne, is unsatisfactory as a Russian zonal index.

Arkell, 1935, p. 339 Pl. xxvi). There may not be specific identity in the strictest sense between any Northwest European and Russian species, but provisionally the Albani zone of Dorset can be equated with some confidence with the Polish and Russian Scythicus zone.

VIRGATUS ZONE: (Nikitin, 1881–1884) The Virgatus zone *sensu stricto* has not so far been found to have any representative in Northwestern Europe. The *Virgatites* characteristic of the zone are unique. Unless they are subsequently found in the St. Albans Head marls and Exogyra beds hitherto classed with the lower part of the Gorei zone (Arkell, 1935, p. 334) there is a gap even in the thick Dorset succession.

BLAKEI ZONE: (Pavlow, 1889) In introducing his zone of *Olcostephanus Blakei* ("*Blaki*") for certain clays between the Virgatus and Fulgens zones of the Moscow dis trict, Pavlow (1889, p. 93, Pl. ii) figured two kinds of ammonites from near Moscow—the evolute *O. blakei* Pavlow, and the involute *O. triplicatus* Blake not Sowerby (= *portlandensis* Cox), side by side with a Swindon specimen identified with the latter species, and another Swindon specimen which he considered closely allied and named *O. swindonensis* Pavlow. After coming to England and studying the abundant giant ammonites from the Portland Stone of England and the Boulonnais, Pavlow was convinced that his Blakei zone was the Russian representative of the Portland Stone; so much so that later (1896; 1907) he called the Russian beds the Giganteus zone, an unfortunate change of name which is better reversed. The Blakei zone is a Russian zone, and its age is best considered on its merits under the original Russian designation (the holotype of *O. blakei* is from near Moscow).

It is easy to decry Pavlow's correlation of this zone and to emphasize the minute points of difference between the few figured Russian and the Northwest European ammonites, but to the present writer a least they seem no more than the differences between geographical subspecies, and Pavlow's figures speak for themselves. If his "*O. triplicatus*" does not represent the involute group of *Kerberites*, and his *O. blakei* the evolute (? *Titanites*) *okusensis* (Salfeld), as figured by Buckman (*e.g.*, *K. trikranus* 1924, Pl. DXXXV; *K? forticosta*, 1925, Pl. DXIIIA; *K? okusensis* (Salfeld)[13] 1926, Pl. DLXX) and recognized by Spath (1936, p. 34, Pl. xvi, fig. 2; Pl. xx, fig. 4; Pl. xxix, fig. 4), at least it still remains for Pavlow's critics to show what they resemble more closely. Pavlow (in Pavlow and Lamplugh, 1892, p. 185) admitted the identity between his *O. triplicatus* and one of the specimens figured as *O. lomonossovi* by Michalski (1890, Pl. x, fig. 2), but the exact horizon of this specimen was not given by Michalski, although (p. 449) he recorded *O. lomonossovi* as commonest in the Virgatus beds. The equivalents of the Blakei zone are more likely to be found in or above the Nikitini zone of the Simbirsk region, which likewise overlies the Virgatus zone. This is the "Beds with *Perisphinctes nikitini*" of Michalski (1890, Pl. xiii) and the Nikitini zone of Haug's table (1898). It was equated with the Blakei zone by Pavlow himself (1889, p. 112);—Pavlow's *Perisphinctes biodini* (of 1889, not 1907) from the Simbirsk district being *P. nikitini*, (*See* Michalski, 1890, p. 232.) Some of the specimens (evidently belonging to several species) figured by Michalski as *Perisphinctes nikitini* bear a strong resemblance to ammonites of equivalent size in the Gorei zone in Eng-

[13] Buckman on this plate named *K. okusensis* as genotype of *Kerberites*, but the genotype had been designated by him in 1924 as *K. kerberus* (Pl. DXX).

land. If the Nikitini and Blakei zones are the same, Blakei is the prior zonal index for Russia.

Pavlow intended to monograph the Northwestern European and Russian Portlandian ammonites. Until this is done, his correlation and especially his remarks in the *Argiles de Speeton* (in Pavlow and Lamplugh, 1892, p. 184–185) should be accepted. The following may be quoted (in translation):

> "A study of the medium-sized ammonites from the English Portland Stone and the corresponding beds in the Boulonnais on the one hand, and the Blakei Zone of Russia on the other, has convinced me that the fauna is the same, although up till now the resemblance has escaped notice. This is because the giant forms found in the Portland Stone and sometimes at Boulogne attracted more attention than the neglected middle and inner whorls. In Russia, on the contrary, collectors have generally made for the small specimens and neglected the large, which are for the most part crushed or in fragments, difficult to extract, and very heavy. In this way the English museums have grown rich in giant ammonites from this zone; but in Russia the same forms are to be seen, not in the museums, but on the surface of the slabs of *Aucella*-sandstone dissected by the Volga near Polivna and Kachpur (Govt. of Simbirsk), and in a brown friable sandstone which overlies the *Virgatus* beds near Moscow."

FULGENS ZONE: (Nikitin, 1881–1884) Concerning the number of *Craspedites* zones recognizable in the Upper Volgian there is some disagreement. The writer retains the Fulgens zone, in spite of Pavlow's (1889, p. 92) opinion that it cannot be separated from the Subditus zone, because it is one of Nikitin's original zones and because Pavlow himself (1889, p. 91) shows *Craspedites* (*Kachpurites*) *fulgens* in a separate bed between the Blakei and Subditus beds at Miovniki near Moscow.

SUBDITUS AND NODIGER ZONES: (Nikitin, 1884) Pavlow (1889, p. 85, etc.), used as alternative zonal indices *Craspedites okensis* (D'Orbigny) and *C.* (*K.*) *kachpuricus*, but Nikitin's original indices take priority and seem appropriate and adequate.[14] Pavlow (1907, table) also has a separate Kachpuricus zone between Nodiger and Riasanensis.

THE JURASSIC-CRETACEOUS BOUNDARY

Muller (1941, Table 1) follows Pavlow (1896, p. 548) in including the zone of *Berriasella* (*Riasanites*) *riasanensis* in the Jurassic, but this is generally regarded as a heresy and has still less justification now that Kilian's report of *B. riasanensis* (Lahusen) in the Upper Tithonian (Transitorius zone) of Southeast France (Kilian, 1895, p. 684) has turned out to be based upon a misidentification (Mazenot, 1939, p. 262). The Ryasan beds are almost universally correlated with the zone of *Berriasella boissieri* (with *B. malbosi*[15]) and placed at the base of the Cretaceous (*e.g.*, Salfeld, 1914, Table II; Kilian, 1895, Pl. xi; Mazenot, 1939, p. 25). Even Pavlow changed his mind when he placed the Riasanensis zone in the Jurassic, for in 1892 (in Pavlow and Lamplugh, p. 194) he thought it Neocomian.

FORMATIONS

The formations and other lithogenetic rock units are, as it were, the bricks out of which the whole structure of stratigraphy is built up. They were the earliest to be

[14] The Okensis zone of Muller's Table 1 is thus a synonym of the Subditus zone shown as overlying it.

[15] The Malbosi zone of Muller's Table 1 is a synonym of the Cretaceous Boissieri zone, not part of the "Privasensis zone" as shown.

named and defined and are still the working units for cartography, water supply, and other economic uses, and all local stratigraphy in each country; and let it not be forgotten that it is just this "local stratigraphy" that forms the basis of the whole science. Any "standard global time-rock sequence" that does not stand the test of minute investigation at a "local exposure" is wrong and must be changed. Further, attempts to tamper with the local scope of formations in any country in the interests of general uniformity are unjustified because they confuse different objectives: stages and zones already exist for international correlation.

Thus when Muller (1901, p. 1434) recommends that the English should expand their Middle Lias to include a large part of the Lower Lias, the suggestion is, in the jargon of zoological nomenclature, "stillborn". The English Middle Lias *is* the zones of *Amaltheus margaritatus* and *Paltopleuroceras spinatum*; it has always been so and is irretrievably standardized as such in the official memoirs published in the nineteenth century (Woodward, 1893–1895). If English geologists now began meaning something different when they used the same words as their fathers and grandfathers, there would be hopeless confusion; and what would be the need for such terms as Pliensbachian? On the other hand, no one is confused by the Germans' different and well-known usage of their Mittlerer Lias nor by the French Lias Moyen.

Similarly, the strongest exception is taken to Muller's recommending to English-speaking geologists that they should adopt and use the terms Dogger and Malm in the German sense as proposed by Oppel, as alternatives to (even with precedence over) the terms Middle and Upper Jurassic respectively. No one objects to German-speaking geologists using the words in this way, and in German texts their meaning is clear. But both words are also used in the English language—and in the English technical vocabulary of geology—with quite different meanings. As used in England, the Dogger means and has meant since at least 1822 (Young and Bird, p. 123) not the Middle Jurassic, but the basal few feet of the Inferior Oölite (of Lower Bajocian age) in Yorkshire only. Similarly, in England the term Malm has never meant Upper Jurassic but has been used for centuries for the Chalk Marl and Upper Greensand (Cretaceous, Cenomanian and Albian). It is still so used, and quotations are known back to the year 1477. If English-writing geologists are now liable to start using these terms in the German sense, nothing but confusion will result. Alternatives for Middle and Upper Jurassic are not needed, but they already exist in English as Lower, Middle, and Upper Oölites. The Jurassic formations above the Lias were called the Oölites or Oölitic series by English geologists at least from Conybeare and Phillips (1822) down to Geikie (1885) and in the great Jurassic memoirs of the British Geological Survey (Woodward, 1893–1895).

Hitherto, whatever uncertainties and vicissitudes the stages and zones have passed through with the progress of stratigraphic investigation, in the background there has always been the unchanging yardstick of the formations, an ultimate court of appeal in each country and each locality. When an English geologist spoke of the Portland beds, or the Purbeck beds (or the Dogger, or the Malm) it was clear what he meant; and so it was if a Frenchman referred to the Calcaire de Caen, or the Oölithe Miliare; or a German to the Heersumer Schichten, or the Hilsthon or the Munder Mergel. Let us beware of needlessly disturbing these firm foundations of our shifting science.

CONCLUSIONS

(1) Stages provide the best medium for correlations of continental scope and for an eventual global time-rock standard.

(2) Zones are units of more restricted purpose and use, but with special advantageous qualities which are lost if the area of their application is expanded farther than the ascertained facts of distribution admit. There must therefore always be separate zonal tables for each faunal province.

(3) Correlation should proceed by paralleling the zonal schemes appropriate to distinct faunal provinces, not by combining them into a synthetic zonal table not based on the facts of observation in any area and therefore corresponding to nothing in nature.

(4) The International Geological Congress should not be asked to approve and stereotype any particular standard sequence of stages or zones, but should be asked to set up a body charged with evolving, if possible, a Code of Rules governing the use of stage names and zonal indices in each geological system.

(5) For the Jurassic system, at least, a Code of Rules analogous with the existing International Rules of Zoological Nomenclature is desirable and practicable for the governance of stage names.

(6) Governance of zonal index species by priority or any other rules should be attempted only with the provisoes that the species chosen be appropriate and occur in the province to which any sequence or table applies.

(7) Formations, the earliest stratigraphic units to be named and the basis of all stratigraphy, are still valuable as ultimate standards of reference. Their scope as defined in their type areas should not be interfered with. Attempts to make their names unifom, or their scope equivalent, will produce more confusion than order.

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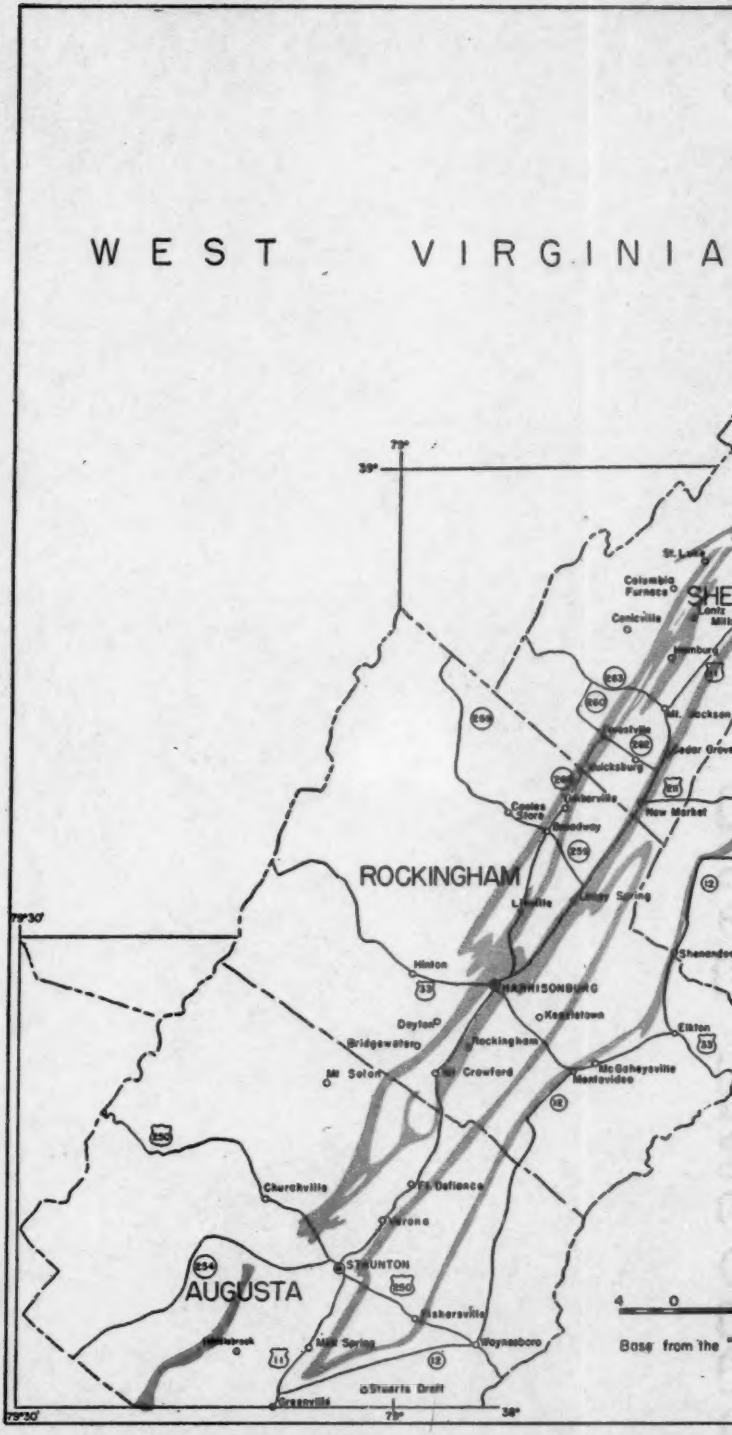

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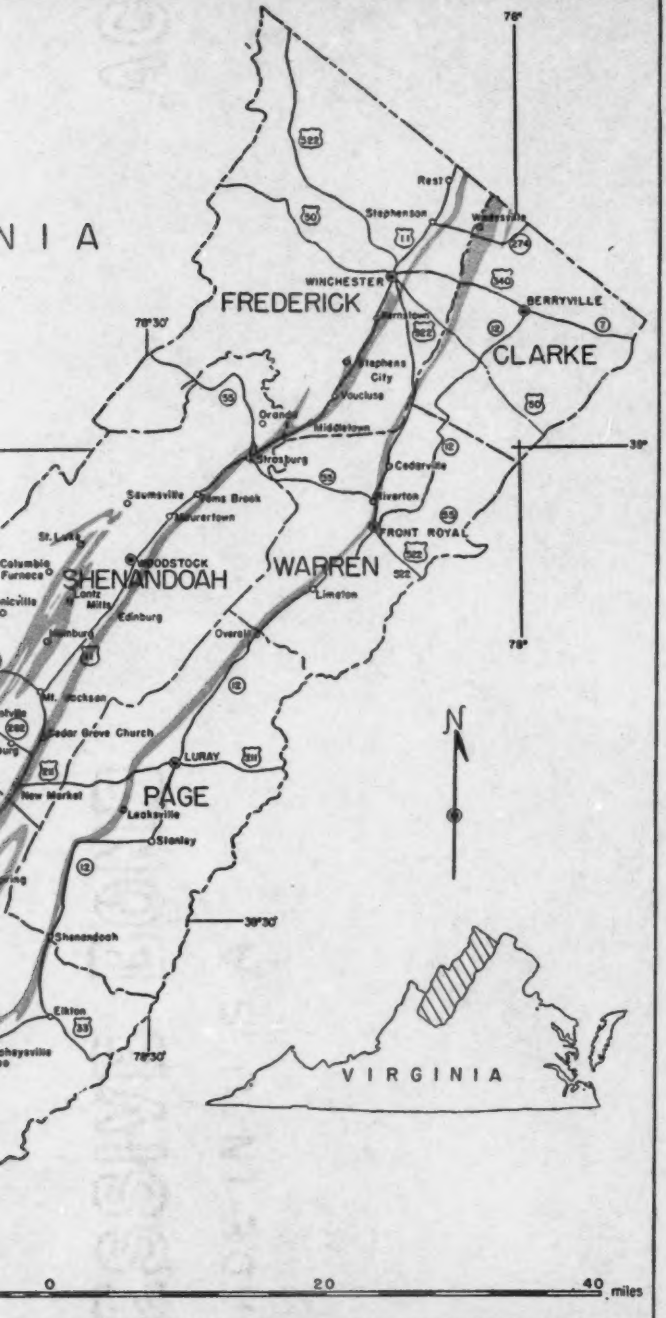

Base from the "Geologic Map of the Appalachian Valley of Virginia," by Charles Butts (Virginia Geological Survey Bulletin 42, 1933)

FORMATIONS IN THE SHENANDOAH VALLEY, VIRGINIA

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LOWER MIDDLE ORDOVICIAN STRATIGRAPHY OF THE SHENANDOAH VALLEY, VIRGINIA

BY BYRON N. COOPER AND G. ARTHUR COOPER

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ABSTRACT

In classifying the lower Middle Ordovician of the Shenandoah Valley, the formation names Stones River, Mosheim, Lenoir, Holston, Whitesburg, and Athens have been used without adequate evidence. Detailed study shows that the so-called Athens and Whitesburg, as developed near Harrisonburg, are laterally continuous with the greater part of the Chambersburg limestone, which is supposed to be younger than the Athens. The newly discovered relations of these formations affect the classification of the Middle Ordovician in much of the northern Appalachian region. The present study has been high-lighted by the discovery that *Cryptophragmus antiquatus*, widely regarded as a valid guide to the lower Black River, ranges through several hundred feet of beds, possibly as high as lower Trenton. In the Shenandoah Valley, this fossil is most abundant near the top of the Chambersburg, which is supposed to be late Black River or early Trenton.

In the proposed reclassification, the lower Middle Ordovician is divided into six time-stratigraphic units, in ascending order: the New Market limestone, Whistle Creek limestone, Lincolnshire limestone, Edinburg formation, Oranda formation, and Collierstown limestone. The Edinburg embraces two equivalent facies: one of cobbly limestone (Lantz Mills facies) which is mainly developed in the northern and western parts of the Shenandoah Valley; and a relatively thicker body of black limestone and shale (Liberty Hall facies) which is typically developed in the Harrisonburg-Staunton area. In the western part of Shenandoah County, the topmost division of the Edinburg formation is composed of light-gray calcilutite and calcarenite, named the St. Luke limestone member. The rusty-brown granular limestones just below Butts' Athens in the Harrisonburg-Staunton-Lexington area are here named the Botetourt limestone member of the Edinburg formation.

At least part of the New Market limestone is linked with a part of the New York Chazy and type Lenoir, but the Lincolnshire seems to be post-Chazy. All the succeeding beds, comprising the greater part of the lower Middle Ordovician succession, are Black River or Trenton.

INTRODUCTION

In preparation of a monograph on Chazy and related brachiopods, G. A. Cooper has made extensive collections of fossils from the post-Beekmantown, pre-Martinsburg formations in the Appalachian Valley. Largely from detailed study of these fossils he tentatively concluded several years ago that the generally accepted classification of the lower Middle Ordovician in the Appalachian region confused time-stratigraphic divisions with purely lithogenic units transcending faunal zones.

The interest of B. N. Cooper in the problems of the Middle Ordovician stratigraphy of northern Virginia developed during field studies of the industrial limestones of

the Shenandoah Valley for the Virginia Geological Survey. The field work work on this project was begun by R. S. Edmundson and during 1943 and 1944 was completed jointly by B. N. Cooper and him. As a result of these studies B. N. Cooper came to the same conclusion previously reached by G. A. Cooper. The outgrowth of frequent interchanges of information and ideas was a field conference during July 1944. Critical sections of the Middle Ordovician in the Shenandoah Valley of Virginia, and in southern Pennsylvania, Maryland, and the adjacent panhandle of West Virginia were examined in detail. This joint study revealed the need for a thorough revision of the stratigraphic nomenclature used in these areas. Two plates of significant and useful fossils show some of the faunal evidence discussed.

FAUNAL AND LITHOLOGIC SUBDIVISIONS

GENERAL STATEMENT

The principal structure in the Shenandoah Valley is a broad synclinal complex from which rises the bold ridges of Massanutten Mountain. These ridges, upheld by unusually thick resistant late Ordovician and early Silurian sandstones, are enclosed by broad expanses of Martinsburg shale, which mark the outer limits of the Massanutten syncline. On the east side of Massanutten Mountain, the Martinsburg shale is bordered by a belt of lower Middle Ordovician limestone and shale 400 to 1000 feet thick, which is steeply upturned and locally repeated by minor folding and faulting. This belt is readily accessible from State Highway 12. The first limestone belt west of the Massanutten syncline closely parallels U. S. Route 11 and is well exposed in a number of places. Between Strasburg, Shenandoah County, and Staunton, Augusta County, the lower Middle Ordovician limestones are repeated in a number of folded, faulted belts, all of which are crossed by numerous roads extending west from U. S. Route 11. Locations of principal towns and roads and the geologic sections mentioned in this paper are shown on Plate 1.

The general character and thickness of the strata above the Beekmantown and below the Martinsburg varies so greatly in the Shenandoah Valley that no single section can be considered typical for the whole district. Since the sections near Harrisonburg, Rockingham County, and near Lantz Mills, Shenandoah County, and near Staunton, Augusta County, offer the maximum contrast in thickness and lithology, they are described in detail, and areas where the characters of these generalized sections prevail are indicated. For convenience, the sections will be divided into informally named faunal-lithologic zones.

SECTIONS NEAR HARRISONBURG

Tetradium syringoporoides *beds*.—Near Harrisonburg, the Beekmantown group is overlain unconformably by a relatively thick zone of uniformly fine-grained dove-gray compact limestone which gives every indication of having been deposited as a lime mud and is therefore properly called calcilutite (Grabau, 1924, p. 295–297). The average thickness is 50 to 150 feet, with the lower third invariably thinner-bedded and somewhat less pure than the overlying massive beds. The contrasting light color of weathered surfaces and the rounded, fluted exposures are distinctive. Be-

cause of its dense, almost porcellanous structure, the calcilutite emits a distinct ring when struck with a hammer and breaks with conchoidal fracture. This is the "quarry rock" of the Shenandoah Valley, which yields large quantities of chemical lime and fluxing stone. Fossils other than the abundant *Tetradium syringoporoides* Ulrich (Pl. 2, fig. 5) are uncommon. Etched outlines of large, high-spired gastropods can generally be seen wherever exposures are sufficiently extensive. Perhaps the finest exposure of these *Tetradium* beds in the general vicinity of Harrisonburg is at the intersection of County Roads 718 and 720, 2 miles east of the town and about 1 mile east of U. S. Route 11.

Dinorthis atavoides *beds.*—Succeeding the *Tetradium syringoporoides* beds is the only commonly cherty limestone in the lower Middle Ordovician. The rock is dark gray, granular, and rather unevenly bedded. A characteristic of most sections is the prevalence of bright-reddish films of iron oxide along the bedding. Coarse-grained calcarenites, generally crowded with *Girvanella*, are intercalated in the cherty layers. Locally, a considerable thickness of light-gray, granular limestone occurs at the base of the zone. In the northeast environs of Staunton, 50 feet or more of coarse-grained, clastic-textured limestone, containing large algal masses, closely overlies the *Tetradium syringoporoides* beds (Geologic section 23), and a similar body of coarse-grained limestone directly succeeds the Beekmantown dolomite half a mile south of the junction of U. S. Route 250 and Road 644, 2 miles southeast of Staunton.

In most sections of the *Dinorthis atavoides* beds, fossils are found chiefly in the weathered, residual chert. The common ones are *Dinorthis atavoides* Willard (Pl. 2, fig. 9), *Sowerbyites triseptatus* (Willard) (Plate 3, figs. 21–23), *Multicostella* cf. *M. saffordi* (Hall and Clarke), *Girvanella* sp., and several bryozoans including *Rhinidictya nicholsoni* Ulrich. Locally, whorls of a large, planispirally coiled gastropod, probably a *Maclurites*, are common on weathered surfaces of the cherty layers. The thickness varies from 15 to about 150 feet and averages less than 75 feet.

Trilobite beds.—In the vicinity of Harrisonburg, as well as in most other sections of the southern Shenandoah Valley, the *Dinorthis atavoides* beds are overlain by a few feet of granular, dark-gray, fossiliferous, mealy-weathering limestone which is generally stained rusty brown. These beds are crowded with the lustrous black fragments of trilobites, mainly species of *Arthrorhachis*, *Bronteopsis*, *Bumastus*, *Homotelus*, *Sphaerexochus*, and *Sphaerocoryphe*. Other fossils, such as *Echinosphaerites aurantium* (Gyllenhahl), *Ptychoglyptus virginiensis* Willard, *Sowerbyella negrita* (Raymond), and *Multicostella bursa* (Raymond), are also distinctive forms. The rusty-brown "trilobite beds" are exceptionally well exposed below Laird Knob on Massanutten Mountain, 1.6 miles south of Bethel Church (formerly known as Paulington) and 6 miles due east of Harrisonburg. Another fine exposure is at Cedar Grove Church, about 1.9 miles N. 82° E. of Harrisonburg.

South of the Shenandoah Valley, in the vicinity of Lexington (Geologic section 40), the "trilobite beds" are about 75 feet thick and locally very shaly. Probably the finest exposure of the shaly phase of the trilobite beds is on a gullied hillside 0.5 mile due south of Dunkard Church and 6.9 miles S. 80° W. of Natural Bridge (Geologic section 43). Here, beds identical in lithology and position to those east of

Harrisonburg yield an uncommonly large number of fossils, including *Echinosphaerites aurantium*, a large species of *Orthambonites*, *Multicostella bursa* (Raymond) (Pl. 2, figs. 7–8), *Sowerbyella negrita* (Raymond), a large *Illaenus*, *Bronteopsis gregaria* Raymond (Pl. 3, figs. 1–2), and a moderately large *Corineorthis*, (Pl. 3, fig. 13).

Black limestone and shale.—Dense, black limestone and black graptolite-bearing shale occur above the dark-gray granular beds. The thickness in the immediate vicinity of Harrisonburg is about 1300 feet, but it is noticeably less a short distance to the north. A pinkish-weathering shaly zone almost invariably occurs at the base, but similar shales occur also at higher levels. The limestones are dense, black, and impure and break with a conchoidal fracture. In most exposures, the limestones are intricately folded and fractured. White calcite, most of which fills systems of en echelon fractures, is abundant and is a reliable guide in recognizing the zone. Weathered surfaces of the limy beds commonly show linear series of small pits resulting from the etching of incipient minute fractures in the rocks. In the northeast environs of Harrisonburg, the black limestones have been quarried and used for black marble.

The shaly beds in the lower part of the zone contain several representatives of the *Nemagraptus gracilis* graptolite fauna, which occurs in the Normanskill shale of the Albany district of New York. The upper part of the zone contains some Normanskill graptolites, but apparently no *Nemagraptus*. The limy beds contain almost no recognizable graptolites, but several trilobites and brachiopods, including species of *Ampyxina*, *Ampyx*, *Lonchodomas*, *Cryptolithus* or *Tretaspis*, *Robergia*, *Dionide*, *Remopleurides*, and *Arthrorhachis*. Among the brachiopods, species of *Ptychoglyptus*, *Oxoplecia*, *Leptellina*, *Multicostella*, *Sowerbyella*, *Dinorthis*, and *Resserella* have been collected.

Nidulites *beds.*—Above the thick body of black limestone and shale is 50 to 100 feet of black, cobbly, argillaceous limestone characterized by abundant *Nidulites* (Pl. 2, fig. 3). Other fossils are relatively uncommon, but specimens of *Christiania* and *Resserella* have been collected. In some sections, particularly northwest of Harrisonburg, the typically cobbly, buff-weathering limestones with abundant *Nidulites* are supplanted by thick beds of dense black limestone with sparse *Nidulites*. Such beds are well exposed at Cedar Grove Church 3.7 miles south of Mt. Jackson; 0.5 mile east of Lacey Spring Post Office; and 0.3 mile west of the junction of State Highway 260 with Road 767, about 2.8 miles N. 8° W. of Harrisonburg. South of Harrisonburg, the *Nidulites* beds merge laterally with the thickened succession of black limestone and black, graptolitiferous shale.

Post-Nidulites *beds.*—Between Harrisonburg and Mt. Jackson, the *Nidulites* beds are succeeded by 30 to 125 feet of limestone containing *Foerstephyllum "halli"* (Nicholson), moderately abundant *Cryptophragmus antiquatus* (Pl. 2, fig. 1), branching sponges or fucoids of the *Camarocladia* type, and numerous gastropods most of which are referable to the genera *Subulites*, *Helicotoma*, and *Maclurites*. These beds are especially well displayed just north of Road 753 about 0.4 mile west of Linville Station on the Southern Railroad, and also at Cedar Grove Church 3.7 miles south of Mt. Jackson. In both places the zone is composed mainly of dense black limestone but with thin partings of coarsely granular calcarenite which con-

tain abundant *Cryptophragmus* and *Camarocladia*. Along State Highway 263, about 2.1 miles N. 63° W. of Mt. Jackson the post-*Nidulites* zone is 125 feet thick and consists entirely of light-gray calcarenite. Southward, these clastic limestones grade laterally, like the underlying *Nidulites* beds, into the thickening succession of black limestone and shale and are not distinguishable in the southern part of the Shenandoah Valley.

Reuschella "edsoni" *beds*.—The topmost division, occurring directly beneath the *Sinuites* zone of the basal Martinsburg, consists of very impure, drab-gray limestone with intercalated beds of brown siltstone, buff shale, and tawny-colored metabentonites. The siltstones are the most distinctive beds and form distinct ledges. However, the fossils rather than the lithology are the most characteristic feature. Besides *Reuschella "edsoni"* (Bassler) (Pl. 3, figs. 33–34), the zone contains a species of *Bimuria* (Pl. 3, figs. 29–32), *Eoplectodonta alternata* (Butts), (Pl. 3, figs. 16–28), *Christiania trentonensis* Ruedemann, *"Sowerbyella" pisum* Ruedemann, *Oxoplecia simulatrix* (Bassler), *Resserella* cf. *R. rogata* (Sardeson), and *Echinosphaerites aurantium* (Gyllenhahl). All these fossils were collected from a single ledge about 20 feet stratigraphically above cobbly, *Nidulites*-bearing limestones in the fields north of Road 721, 0.5 mile west of the Southern Railroad station at Linville, Rockingham County. This zone, averaging about 30 feet thick, marks the transition between the underlying limestones and overlying shales and siltstones.

SECTIONS NEAR LANTZ MILLS

Tetradium syringoporoides *beds*.—In the vicinity of Lantz Mills, Shenandoah County, the Beekmantown is overlain by 50 to 200 feet or more of fairly pure, dove-gray calcilutite, thin-bedded near the base and thick-bedded to massive in the upper two thirds. The zone is identical to that above the Beekmantown in the vicinity of Harrisonburg. The variations in thickness reflect the irregular surface upon which the beds were deposited. Locally a few feet of conglomeratic, magnesian limestone occurs at the base.

Dinorthis atavoides *beds*.—As in the Harrisonburg area, the *Tetradium* beds are overlain by characteristically cherty limestones containing *Sowerbyites*, *Dinorthis*, and *Multicostella*. The thickness ranges from 75 to 150 feet and averages about 100 feet. Intercalated beds of coarse-grained clastic limestone with *Girvanella* are somewhat more abundant than they are in the vicinity of Harrisonburg.

Lower Echinosphaerites *zone*.—Very argillaceous, nodular-weathering, fossiliferous limestones aggregating 50 to 150 feet overlie the *Dinorthis atavoides* beds. Although *Echinosphaerites* is perhaps the most characteristic fossil, it occurs in profusion in but a few layers. Other fossils include:

Brachiopods
- *Christiania* sp.
- *Corineorthis* sp.
- *Dinorthis transversa* Willard
- *"Sowerbyella" pisum* Ruedemann
- *Multicostella* cf. *M. bursa* (Raymond)
- *Opikina "minnesotensis"* (Winchell)
- *Oxoplecia* cf. *O. simulatrix* (Bassler)
- *Ptychoglyptus virginiensis* (Willard)
- *Resserella* cf. *R. rogata* (Sardeson)

Bryozoans
Chasmatopora and related genera
Trilobites
Ampyx sp.
Arthrorhachis cf. *A. elspethi* Raymond
Bronteopsis gregaria Raymond
Ceraurus pleurexanthemus Green
Homotelus cf. *H. simplex* (Raymond and Narraway)
Lonchodomas sp.
Sphaerocoryphe sp.
Tretaspis or *Cryptolithus*

Nidulites cf. *N. pyriformis* Bassler occurs rarely in the upper part of the zone.

Between Maurertown, Shenandoah County, and Winchester, Frederick County, a ridge-making thin siltstone (Edmundson, 1939, p. 99–104) occurs near the base of the lower *Echinosphaerites* beds. Several metabentonites are commonly associated with the distinctive siltstone. These beds are well exposed along Tumbling Run, 1.8 miles S. 75° W. of Strasburg, Shenandoah County. In many places, a few feet of granular limestone crowded with trilobites occurs at the base.

Nidulites-Lambeophyllum *beds.*—The succeeding zone, composed of slabby to cobbly argillaceous limestones, is characterized by a profusion of *Nidulites pyriformis* Bassler and the distinctive cup coral, *Lambeophyllum profundum* (Conrad). In many sections, especially where the dips are steep, these two fossils are about the only ones commonly found. Other fossils collected from this zone include: *Resserella* cf. *R. rogata* (Sardeson), *Christiania* cf. *C. trentonensis* Ruedemann, *"Sowerbyella" pisum* Ruedemann, *Ampyx* sp., *Arthrorhachis* sp., *Bronteopsis* sp., *Lonchodomas* sp., *Homotelus* sp., *Receptaculites* cf. *R. occidentalis* Billings, *Camarocladia* sp., and *Cryptophragmus antiquatus* Raymond. The thickness of this zone ranges from 100 to 300 feet.

*Post-*Nidulites *beds.*—The *Nidulites-Lambeophyllum* zone and the *Reuschella "edsoni"* beds are separated by a variable thickness of sparingly fossiliferous limestone. In the limestone belt paralleling U. S. Route 11 between Edinburg and Woodstock, the post-*Nidulites* beds are 10 to 75 feet thick and consist of black, rather evenly bedded limestone with thin partings of light-gray calcarenite. In the belts to the west, between Forestville and Saumsville, the post-*Nidulites* beds are composed of 75 to 125 feet of distinctive light-gray limestone. Near St. Luke, the zone is practically all calcilutite, but in the sections 2 miles west of Lantz Mills only the uppermost 20 feet is calcilutite, the rest being medium-grained calcarenite.

Fossils are not common, but locally west of Lantz Mills *Cryptophragmus antiquatus* Raymond, *Foerstephyllum "halli"* (Nicholson), and *Doleroides* sp. were collected. The black, slabby limestones, composing the post-*Nidulites* zone in the belt along U. S. Route 11, likewise contain *Cryptophragmus antiquatus, Subulites* sp., and *Camarocladia* sp.

Reuschella "edsoni" *beds.*—The topmost division of the Middle Ordovician limestones near Lantz Mills is identical to that in the vicinity of Harrisonburg. It is composed largely of impure, buff-weathering limestones, brown siltstones, and bentonitic shales, containing *Reuschella "edsoni"* and its associates. The total thickness is about 30 feet. The zone is sharply overlain by the distinctive *Sinuites* beds of the basal Martinsburg.

SECTIONS NEAR STAUNTON

Rostricellula *bed.*—In the east end of the quarry of the Staunton Lime Company, in the northeast environs of Staunton, the Beekmantown dolomite is succeeded by a few feet of light-gray coarse-grained calcarenite abounding in *Rostricellula pristina* (Raymond). The contact between this bed and the underlying dolomite is very irregular, and locally the fossiliferous limestone fills fractures extending a foot or more into the dolomite. The only other place where this *Rostricellula* bed has been identified is in the section near Montevideo, Rockingham County (Geologic section 29). The fact that the bed with *Rostricellula pristina* occurs below the base of the *Tetradium syringoporoides* zone in the quarry of the Staunton Lime Company suggests that it is the oldest division of Middle Ordovician limestone in the Shenandoah Valley. However, possibly the basal layers of dove limestone with *Tetradium syringoporoides* which elsewhere directly succeed the Beekmantown were deposited at about the same time as the *Rostricellula* bed of the Staunton quarry.

Tetradium syringoporoides *beds.*—In most other exposures in the vicinity of Staunton, the Beekmantown dolomite is succeeded by 25 to 60 feet of dove-gray calcilutites containing *Tetradium syringoporoides.* Locally, about 3.5 miles west of Staunton, the basal layers are pinkish and dolomitic and resemble the Blackford beds of southwestern Virginia (Geologic section 31). In general, the *Tetradium syringoporoides* beds are not so thick nor quite so pure as they are farther north, in Rockingham, Shenandoah, and Frederick counties. However, in a few sections about 7 miles south of Staunton, the *Tetradium syringoporoides* beds are 110 to 130 feet thick and exceptionally pure. Near DeJarnette Sanatorium, in the southeast environs of Staunton, the *Tetradium* beds are absent, but this is the only locality in the Staunton area where no representative of this zone occurs. The zone is well exposed in the quarries near Staunton and in the quarry half a mile west of U. S. Route 11 and just north of Middle River, in the vicinity of Verona, Augusta County.

Hesperorthis *beds.*—In the Staunton area, the dove-gray calcilutites with *Tetradium* are overlain by dark-gray cherty limestones containing distinctive species of *Hesperorthis, Mimella, Valcourea,* and *Camerella* and *Multicostella saffordi.* The lithology of this zone is practically the same as that of the *Dinorthis atavoides* beds, but the beds are somewhat thinner and more irregular. Many bedding surfaces are coated with rusty-brown to crimson-red films of iron oxide. In sections near the southern tip of the Massanutten syncline, the *Hesperorthis* beds are 60 to 80 feet thick, but the zone thins northward pinching out in the immediate vicinity of Staunton. This division has not been recognized in any section in the northern and middle parts of the Shenandoah Valley. The best exposures are (1) along U. S. Route 250 about 3.5 miles west of Staunton (Geologic section 31); (2) in a quarry along Road 608 about a quarter of a mile east of the intersection with Road 652, about 6.7 miles S. 20° E. of Staunton; and (3) along Road 602 about 5.5 miles S. 80° W. of Middlebrook, Augusta County. In the latter locality, *Dinorthis holdeni* (Willard), leading fossil of the "blocky chert" of Tazewell County, is a striking addition to the *Hesperorthis* fauna (Geologic section 38).

Granular beds.—A few miles south of Staunton (Geologic sections 34–37), the *Hesperorthis* beds are succeeded by coarse-grained clastic limestones. The maximum

thickness of these calcarenites is about 175 feet (Geologic section 36), but the zone thins rapidly northward and is only 20 feet thick in the quarry along Road 608 about 6.7 miles S. 20° E. of Staunton (Geologic section 34). About 1200 feet southwest of the main buildings of DeJarnette Sanatorium near Staunton, the light-gray granular calcarenites directly overlie the Beekmantown. The fact that the overlying zone with *Dinorthis atavoides* is abnormally thin wherever the granular beds are well developed, and the presence of granular intercalations in the cherty beds of the *Dinorthis atavoides* zone suggest that the granular beds are a calcarenitic or reefy facies of the typically cherty *Dinorthis* zone. The best exposure is along the spur of the Chesapeake Western Railroad, near the stock yards, in the east environs of Staunton.

Dinorthis atavoides *beds.*—In the Staunton area, the *Dinorthis* beds are essentially the same as in other parts of the Shenandoah Valley. The fact that the *Dinorthis* beds just south of Staunton are separated from the *Tetradium syringoporoides* beds by 50 to over 200 feet of beds indicates that there is probably an unconformity between the *Dinorthis atavoides* zone and the underlying zone of dove limestone in the middle and northern parts of the Shenandoah Valley. West of Staunton along U. S. Route 250, the *Dinorthis* and *Hesperorthis* zones can be distinguished only by fossils.

Trilobite beds.—The few feet of granular rusty-weathering impure limestone succeeding the *Dinorthis atavoides* zone in the Staunton area is essentially the same as in the Harrisonburg area. The thickness of this division probably does not exceed 25 feet anywhere in the vicinity of Staunton and probably averages less than 10 feet.

Black shale and limestone.—Exposures of the thick zone of black shale and limestone are poor in the Staunton area. The zone is probably less than 1500 feet thick in the belts between Staunton and Fishersville, where black shale almost completely supplants black limestone and grades imperceptibly upward into the buff sandy shales of the Martinsburg formation. Black shales near the base of the zone contain representatives of the *Nemagraptus gracilis* fauna, but most of the succeeding beds are practically devoid of fossils. In the belts west of Staunton, particularly in the exposures along the base of Little North Mountain south of U. S. Route 250, the zone is composed principally of black limestone. Much of this rock closely resembles the slabby limestones comprising the middle and upper parts of the Chambersburg limestone along Tumbling Run, near Strasburg, Shenandoah County. These slabby beds with an aggregate thickness of about 500 feet contain *Ampyx*, *Ampyxina*, *Calliops*, *Homotelus*, *Dinorthis transversa*, *Resserella*, and *Echinosphaerites*.

Nidulites *beds.*—In the immediate vicinity of Staunton, the zone of black shale and limestone comprises the uppermost division of the lower Middle Ordovician below the Martinsburg. West of Staunton, along the base of Little North Mountain, the 500 feet of black slabby limestone is succeeded by 30 to 60 feet of similar limestone containing an abundance of *Nidulites pyriformis*. This fossil is unknown in the sections close to Staunton, but possibly the limestones containing this fossil are represented by some of the black shales just below the Martinsburg in the Staunton area.

Zygospira *beds*.—Along Little North Mountain south of U. S. Route 250, west of Staunton, the *Nidulites* beds are separated from the Martinsburg by 30 to 65 feet of medium-grained shell limestone, layers of which are crowded with *Zygospira recurvirostris*, *Doleroides*, *Sowerbyella*, *Parastrophina*, and *Cyclospira*. Probably the most significant fossil, which occurs sparsely in a few layers, is a form of *Rafinesquina* s.s., a genus unknown below the Trenton. The *Zygospira* beds apparently do not extend as far north as the area containing the *Reuschella "edsoni"* zone, and their relation and position with respect to this zone are unknown. The *Zygospira* beds are more prominently developed farther south, in the western limestone belts of Rockbridge and Botetourt counties, in the James River district.

SUMMARY

The *Tetradium syringoporoides* beds and the succeeding *Dinorthis atavoides* zone are persistent units easily recognizable throughout the Shenandoah Valley. The overlying thick body of black limestone and shale, occurring in the Harrisonburg area, can be traced as far north as Mt. Jackson and Forestville, Shenandoah County, on the west side of the Massanutten syncline. On the east side of the Massanutten syncline, southwest of Front Royal, Warren County, black graptolitiferous shales occur to the almost complete exclusion of the characteristic dense black limestones of the Harrisonburg region. The black shales and black limestones are complementary parvafacies.

The cobbly limestones of the Lantz Mills section are typically developed only in the western belts of Shenandoah County. Elsewhere the interval above the *Dinorthis atavoides* zone and below the *Reuschella "edsoni"* zone exhibits alternations of dense black limestone and cobbly beds. South and east of Harrisonburg, the entire succession above the "trilobite beds" and below the Martinsburg is black limestone and shale. The upper part of this sequence is believed to contain equivalents of the *Nidulites* and post-*Nidulites* beds as developed northwest of Harrisonburg.

PREVIOUS INTERPRETATIONS

Bassler (1909, p. 51–122) published the first detailed description of the Ordovician limestones of the Shenandoah Valley. In the vicinity of Strasburg, Bassler included in the Chambersburg limestone all the beds below the *Sinuites* zone of the Martinsburg shale and above the *Tetradium* beds. The *Tetradium* beds and 800 feet or so of the underlying dolomite and limestone succession were referred to the Stones River.

Geologic section 1.—Ordovician limestones in the vicinity of Strasburg, Shenandoah County, Virginia (after Bassler, 1909, p. 56)

	Thickness Feet
Martinsburg shale	
Chambersburg formation, about 400 feet of blue and argillaceous limestones arranged in the following order:	
(i) Earthy gray limestone and calcareous shales	40
(h) Light-gray earthy limestone	30
(g) Massive dove limestone	65

	Thickness Feet
(f) Rather thin-bedded dove limestone	60
(e) Thin-bedded dark-gray argillaceous limestone	52
(d) Thin-bedded argillaceous black limestone	22
(c) Nodular argillaceous dark-blue limestone	30
(b) Crinoidal limestone	10
(a) Siliceous blue limestone, cherty in the upper part but pure in the lower portion	80
Stones River formation, about 900 feet of more or less pure and magnesian limestones, the upper 100 feet consisting of heavily bedded, pure dove limestone, with occasional black layers, alternating with magnesian limestone	900
Typical Beekmantown dolomite, weathering into characteris chert	—

Farther south, in the vicinity of Harrisonburg, Bassler (1909, p. 91) believed the same body of limestone is present but much thinner. The *Christiania* [*Reuschella*][1] bed directly beneath the Martinsburg was described as similar in appearance and fossils to the same zone at Strasburg (Geologic section 1, unit 31). Beneath this zone, Bassler recognized 100 feet of *Nidulites*-bearing limestone, which was said to overlie 200 feet of pure and magnesian limestones of Stones River age. Along U. S. Route 33, about 9 miles west of Harrisonburg, Bassler (1909, p. 95–97) recorded a greater thickness of Ordovician limestone, including an undetermined thickness of Stones River limestone at the base, 300 feet of overlying, thin-bedded black limestone and shale, referable to the Chambersburg, and at the top 300 feet of fossiliferous limestone of Trenton age and classed with the Martinsburg formation.

In the belt on the east side of the Massanutten syncline, Bassler (1909, p. 74, 94) thought that the thick body of black limestone and shale represents the Chambersburg formation.

Near Wadesville, Clarke County, he classed the *Girvanella*-bearing limestones below the thick zone of black limestone and shale with the Chambersburg formation (Geologic section 2, unit 3).

Geologic section 2.—Middle Ordovician limestone near Wadesville, Clarke County, Virginia (after Bassler 1909, p. 74)

	Thickness Feet
Martinsburg shale: gray, black, and olive shales	—
Chambersburg formation:	
4. Dark-blue and black, compact argillaceous limestone	400
3. Coarsely crystalline grayish-blue limestone	70
Stones River formation:	
2. Gray, dolomitic limestone with intercalated pure dove-colored layers, base not observed. These Stones River limestones have much the same characters described for the formation in other sections of this part of Virginia. The rock may be identified by its numerous *Tetradium* markings and by the presence of the ostracod *Leperditia fabulites*	—
Beekmantown limestone:	
1. Gray dolomitic, cherty limestone	—

No other sections of Ordovician limestone on the east side of the Massanutten syncline were described by Bassler, but the graptolite-bearing black shales and lime-

[1] The *Christiania* defining this bed is now referred to the genus *Bimuria* Ulrich and Cooper.

stones at Riverton, Warren County, were called Chambersburg, and the dove-gray limestone lower in the section was classed with the Stones River (1909, p. 87–88). In the vicinity of Staunton, Bassler (1909, p. 114–119) identified the coarse-grained limestone at the base of the *Dinorthis atavoides* zone as Murat limestone and, all the succeeding beds up to the Martinsburg shale were classed with the Liberty Hall formation. Apparently, the dove-gray *Tetradium* beds directly above the Beekmantown were considered part of the †Natural Bridge limestone.

Giles (1927, p. 42–45) recognized three divisions of the Stones River formation of Frederick County, in the northern part of the Shenandoah Valley. These divisions, which were supposed to be readily distinguishable faunally and lithologically, consisted of: (1) about 600 feet of limestone and magnesian layers, at the base, identified as equivalent to the Murfreesboro limestone of central Tennessee; (2) a middle, cherty division about 150 feet thick, correlated with the Pierce and Ridley of the Central Basin; (3) a similar thickness of dove-gray, *Tetradium*-bearing limestone identified as Lebanon. No basis for the correlations was given. Giles also recognized four divisions in the overlying Chambersburg limestone. The lower division, said to contain *Tetradium cellulosum* and to be 90 to 100 feet thick, was described as ". . .fine-grained to coarse-grained, sometimes distinctly granular, limestone, dark gray to dark blue to black, rarely dove color" (Giles, 1927, p. 44). The identity of this division is not clear, because the only *Tetradium*-bearing division of the Ordovician limestone in Frederick County is the unit which Giles identified as the upper, or Lebanon, division of the Stones River. The three succeeding zones of the Chambersburg, identified by Giles, were the *Echinosphaerites* zone, *Nidulites* zone, and the *Christiania* bed.

Metabentonites in the lower part of the Martinsburg and upper Chambersburg near Strasburg have been described by Rosenkrans (1933, p. 413–419). In the well-exposed section along U. S. Route 11 about 0.25 mile west of the bridge across Tumbling Run, Rosenkrans assigned the *Reuschella "edsoni"* zone to the lower Martinsburg. Following the original definition of the Chambersburg, the *Reuschella "edsoni"* zone—the *Christiania* bed—should have been classified with that formation. This mistake is a source of confusion concerning the correlations set forth by Rosenkrans.

Kay (1935, p. 231–233, Pl. 22) studied the section along Tumbling Run, near Strasburg, and concluded that the *Nidulites* and *"Christiania"* zones correlated with the Rockland-Hull portion of the New York Trenton. He referred the lower part of the Chambersburg to the Lowville-Chaumont interval of the Black River group. The underlying cherty limestones were identified as Lenoir and assigned to the Chazyan. According to Kay (1935, p. 232) the lower 95 feet of the Chambersburg along Tumbling Run is characterized by *Tetradium cellulosum* and contains other fossils suggestive of Lowville age. The dove-gray calcilutites containing *Tetradium cellulosum* in the type section of the Chambersburg are not present in the Tumbling Run section. The writers made a thorough search for this fossil in the lower part of the Chambersburg along Tumbling Run, but no specimens were found. The other fossils occurring in the lower Chambersburg of this section and in the exposures near Strasburg Junction (Geologic sections 19–20) are found in the cobbly limestones

of the *Echinosphaerites* beds of the type Chambersburg, which overlie the *Tetradium cellulosum* calcilutites (Lowville of Stose and others).

Although the formation names in current use did not originate with Butts, the present classification for the lower Middle Ordovician of the Shenandoah Valley was introduced (Butts and others, 1932, p. 40–49) and was subsequently elaborated upon by him, without significant modifications (Butts, 1933, p. 13–20, map; 1940, p. 119–201). His classification is the result of his regional interpretations of the Middle Ordovician in the Appalachian Valley from Pennsylvania to central Alabama. Throughout the Shenandoah Valley, Butts has identified the dove-gray *Tetradium syringoporoides*-bearing calcilutite as the Mosheim limestone (1940, p. 111–114, 136–139) and the overlying cherty limestone as Lenoir. The light-gray, pure limestone, overlying the *Dinorthis* beds in the vicinity of Lexington, Rockbridge County, and in the southernmost parts of the Shenandoah Valley, has been called Holston. The succeding thin dark-gray coarse-grained limestone, extending as far north as Mt. Jackson and Forestville, in Shenandoah County, Butts called the Whitesburg. In the same area, the thick body of black limestone and shale was identified as Athens. The succeeding *Nidulites* beds and the zone of shaly silty limestone containing *Christiania* [*Bimuria*] and *Reuschella* "*edsoni*" were classed with the Chambersburg limestone. According to Butts (1940, p. 164), the thick body of black limestone and shale thins to the northeast and, on the western side of the Massanutten syncline, wedges out near Broadway and Mt. Jackson. On the east side of the syncline, the Athens black limestone and shale were regarded as extending much farther north, past Riverton, possibly as far as the West Virginia line. The Whitesburg was identified locally in a section near the mouth of Narrow Passage Creek 3–4 miles south of Woodstock, and the possibility that the 50 feet of cobbly limestone directly beneath his basal Chambersburg along Tumbling Run, southwest of Strasburg, represents the Whitesburg was considered (Butts, 1940, p. 155). Butts believed the Athens was absent in the Tumbling Run section and referred to the Chambersburg limestone all the succession beginning 80 feet below the siltstone and extending up to the base of the *Sinuites* zone.

During June and July 1943, Butts, investigating further the relationship of the Athens to the Chambersburg in the Shenandoah Valley, concluded that the Athens pinches out near Mt. Jackson and is unconformably overlapped by the Chambersburg limestone. At the close of this investigation B. N. Cooper in company with Butts and Edmundson examined several sections of the Middle Ordovician between Tumbling Run and Lacey Springs, but Cooper did not agree with Butts that the Athens pinched out to the north. The possible interfingering of Butts' typical Athens of the Harrisonburg area with the bulk of the Chambersburg as developed along Tumbling Run seemed to be a plausible, alternative interpretation.

Craig (1942) has subdivided the Chambersburg of southern Pennsylvania into three formations—in ascending order, the Shippensburg limestone, Mercersburg limestone, and Greencastle formation. The Greencastle was named by Bassler (1919, p. 149–154) and was defined as overlying the *Christiania* bed. In Virginia, the *Sinuites* bed of the basal Martinsburg directly succeeds the "*Christiania*" bed, and no beds in the supposed position of the Greencastle have been found. Shippensburg and Mercersburg have no validity, because the names were mentioned

only briefly in an abstract, with no sufficiently detailed account of their faunas or lithologic characters to warrant use of the names by others.

ANALYSIS OF PREVIOUS WORK

STONES RIVER

The name Stones River was introduced into the northern Appalachian region by G. W. Stose (1909) largely at the behest of Ulrich who had come to regard the Stones River of central Tennessee to be represented in the Appalachian region by limestones immediately above the Beekmantown. Stose's Stones River formation of Pennsylvania was described as follows:

Geologic section 3.—Section of basal beds of Stones River limestone at Martinsburg, West Virginia, measured by Ulrich and Stose (1909)

	Thickness Feet
4. Light to dark drab limestone banded with thin earthy or magnesian seams	275
3. Similar beds, not well exposed	200
2. Dark-gray to dove-colored fine even-grained pure limestone (quarried)	100
1. Similar fine-grained dove-colored limestone, increasing downward in magnesium (quarried)	100

The beds which Stose called Stones River are almost continuously exposed along a creek, just north of the type section of the Chambersburg formation.

Geologic section 4.—Post-Beekmantown, pre-Chambersburg limestones near the Cumberland Valley Railroad, about 2 miles southwest of Marion, Franklin County, Pennsylvania

	Thickness Feet
Chambersburg limestone (as emended by Butts and others, 1932, p. 16)	
Pre-Chambersburg beds (including Stose's Lowville and Stones River; 1042 feet)	
16. Calcilutite, light-gray, with *Tetradium cellulosum*	63
15. Limestone, dove-gray pure layers and drab-gray magnesian layers interbedded	17
14. Limestone, dark-bluish gray, fine-grained, contains nodules of black chert	39
13. Calcilutite, medium-bedded, dove gray, contains *Tetradium cellulosum*	135
12. Limestone, fine-grained, drab gray, magnesian	10
11. Calcilutite, dove gray, thick-bedded	28
10. Calcilutite, dove gray, thin-bedded; includes thin intercalations of dark-bluish gray limestone; *Leperditia* and single-tubed *Tetradium* at the top	66
9. Limestone, dark gray, medium- to fine-grained, very cherty; contains *Camerella*, *Öpikina*, and *Mimella*	77
8. Limestone, medium-bedded, bluish gray, sparsely cherty	99
7. Limestone, dark gray, medium-grained, contains *Camerella* and *Öpikina* near the middle; very cherty	138
6. Limestone, very cherty at top, bluish gray; contains *Hesperorthis*, *Multicostella saffordi*, and a small *Sowerbyella*	140
5. Limestone, bluish gray, granular, contains *Maclurites magnus* and "*Camerella*" *longirostris*	21
4. Limestone, very cherty, bluish gray	62
3. Limestone, bluish gray, granular, contains *Maclurites*	17
2. Limestone, dark gray, fine-grained	70
1. Calcilutite, dove gray to light bluish gray; weathers with a thin chalky crust; contains several *Lophospira*-type gastropods and *Tetradium syringoporoides*; lower surface markedly undulatory	30–60
Beekmantown group	

Part of the 358-foot succession of dove-gray fine-grained limestones (units 10 to 16) was assigned by Stose (with Ulrich's agreement) to the Stones River, but the upper 150 feet, said to contain *Tetradium cellulosum* and *Leperditia* aff. *L. fabulites* abundantly and also *Orbignyella wetherbyi*, *Strophomena* cf. *S. emaciata*, *Zygospira recurvirostris*, *Protorhyncha* sp., *Leperditella tumida*, *Isotelus*, *Calliops callicephalus*, and *Ceraurus pleurexanthemus*, all Black River or higher fossils, was made the basal division of the Chambersburg.

Stose (1909, p. 7) and Ulrich also measured 675 feet of Stones River limestone at Martinsburg, West Virginia, but their interpretation of the Martinsburg section seems to be in error, as indicated by Woodward (1939, p. 102). As is well shown in the east environs of Martinsburg, the pure dove-gray calcilutites, which have been extensively quarried, directly underlie the Chambersburg limestone, whereas Stose and Ulrich identified 475 feet of Stones River limestone above the quarry beds and below the Chambersburg.

Use of the name Stones River was later extended into Maryland and Virginia by Bassler (1919, p. 117–129). At Wilson, 7 miles west of Hagerstown on U. S. Route 40, and also near Pinesburg Station along the Western Maryland Railroad, near Williamsport, Maryland, he identified the dove-gray limestones directly beneath the *Echinosphaerites* beds of the Chambersburg as the upper division of the Stones River limestone (Geologic section 5).

Geologic section 5.—Pre-Chambersburg limestones along U. S. Highway 40, Wilson, Maryland

	Thickness Feet
Chambersburg limestone (about 325 feet fully exposed).	
Pre-Chambersburg, post-Beekmantown limestones (541 feet)	
17. Calcilutite, dark gray	48
16. Calcilutite, with buff-gray clayey partings; contains *Tetradium cellulosum*	11
15. Limestone, mealy to dark gray, with buff clayey stringers	4
14. Calcilutite, dove gray, with buff partings	8.5
13. Calcilutite, dove gray; contains *Tetradium cellulosum*, cephalopods, and abundant *Leperditia fabulites*	2.8
12. Limestone, finely granular; buff mealy partings	14
11. Limestone, dove gray, laminated; contains thin partings of buff clayey limestone	9
10. Limestone, medium-grained, drab gray striped with buff-gray clayey partings; *Tetradium* abundant	38
9. Limestone, finely granular, slightly magnesian	1.5
8. Calcilutite, dove gray, laminated	1.5
7. Limestone, finely granular, light bluish gray, thin and irregularly bedded; contains partings of magnesian limestone	45
6. Magnesian limestone and dolomite, buff gray; contains intercalated thin beds of dove-gray calcilutite	9
5. Limestone, dark bluish gray to brownish gray, very fine-grained, dense; contain ribbon bryozoans and *Girvanella*	23
4. Limestone, very finely granular, light gray, rather thin-bedded; beds are thin and very irregular	55
3. Limestone, very finely granular, pearl gray; lower part faintly laminated	74
2. Limestone, finely granular, medium gray	73.5
1. Calcilutite, dove gray, thick-bedded; contains large gastropods and *Tetradium syringoporoides*	123
Beekmantown dolomite and limestone	

The fine-grained beds so identified in the Maryland sections are lithologically and faunally indistinguishable from the upper part of the 358-foot section of dove-gray, *Tetradium cellulosum*-bearing limestones beneath the type Chambersburg, 2 miles southwest of Marion, Pennsylvania. In other words, beds apparently the same as those identified as lower Chambersburg and interpreted to be of Lowville age in the section near Marion, Pennsylvania, were identified as Stones River limestone in Maryland.

Bassler's assignment of 900 feet of beds to the Stones River along Tumbling Run, southwest of Strasburg, Virginia, was apparently based on the assumption that the thick section of fossiliferous limestones beneath the type Chambersburg of Pennsylvania persisted southward into Virginia. Actually, only 175 to 180 feet of post-Beekmantown, pre-Chambersburg limestone occurs along Tumbling Run, southwest of Strasburg.

In the vicinity of Harrisonburg, Bassler referred the relatively thick body of *Tetradium syringoporoides*-bearing calcilutite and the overlying cherty limestone to the Stones River. The usage of the name was not the same as at Strasburg, where the cherty, *Dinorthis atavoides* beds were considered the basal division of the Chambersburg.

In spite of repeatedly asserted correlation of the 1000-foot succession of limestone above the Beekmantown and below the Chambersburg in southern Pennsylvania with the Stones River of Tennessee, no substantial evidence was ever submitted in support of it. As recently shown (B. N. Cooper, 1945, p. 262–275), the true Stones River equivalents in the Appalachian region are not at the base of the lower Middle Ordovician. The Stones River seems clearly to be post-Chazyan and is very probably represented in the Chambersburg. Giles' (1927) claims of the existence of easily identifiable correlatives of the Murfreesboro, Pierce-Ridley, and Lebanon are not supported by any field evidence.

MOSHEIM AND LENOIR

No stratigraphic names are more deeply embedded in Appalachian stratigraphy than Mosheim and Lenoir. Until recently (Cooper and Prouty, 1943), these two formations, as identified by Butts (1933; 1940; Butts and others, 1932), have been generally considered distinctive and readily identifiable stratigraphic units which are persistent throughout the middle and southern portions of the Appalachian Valley. Actually these two units have been misidentified in much of the Appalachian Valley of Virginia, and confusion regarding these formations has resulted in misidentification of many of the succeeding formations. The relationship of the type Lenoir to the type Mosheim needs clarification and was investigated by the writers in 1944.

At Mosheim, Tennessee, the dove limestone just above the Knox dolomite is overlain by 5–10 feet of impure granular crumbly-weathering limestone containing a few orthoid brachiopods, *Mimella* and *Valcourea*, and trilobites, which correlate these beds with the middle beds of the type Lenoir. The type Mosheim therefore occupies the stratigraphic position of the lowest division of the type Lenoir. Since the basal Lenoir at Lenoir City, contains intercalations of dove-gray limestone

resembling the Mosheim, it is not unlikely that the type Mosheim is equivalent to part of the Lenoir.

In the limestone belt which passes through Lenoir City and Philadelphia, Tennessee, the type Lenoir directly overlies the Knox dolomite and exhibits a distinct three-fold development. The lower 15 to 25 feet is composed chiefly of mealy-weathering dolomitic mudrocks with intercalated beds of dove-gray calcilutite. The middle division, 25–45 feet thick, is impure limestone containing *Mimella nuclea* (Butts), distinctive but undescribed species of *Valcourea* and *Hesperorthis*, and the characteristic coral *Billingsaria parva*. The upper 100 to 125 feet is dark-gray, medium-grained, sparsely cherty limestone with *Maclurites "magnus"* the only common fossil. In the exposures between U. S. Route 11 and the Southern Railway 1½ miles southwest of Philadelphia, the limestones of the lower division of the Lenoir grade vertically and laterally into dolomitic mudrock. In the type exposures at Lenoir City, 4–9 feet of dove-gray limestone, not unlike beds elsewhere called Mosheim, occur at the base of the Lenoir and are overlain by 7.5 feet of dolomitic mudrock. The basal Lenoir calcilutite and these mudrocks are separated by 2–18 inches of shaly limestone crowded with *Rostricellula pristina* (Raymond) (Pl. 2, fig. 17). The lithologic similarity, stratigraphic position, and the occurrence of this fossil correlate the lower dolomitic division of the typical Lenoir with the lower Blackford of southwestern Virginia. If the calcilutite at the base of the type Lenoir were to be called Mosheim, the identification would have to be based wholly on lithologic resemblance which is not very pronounced. Near Friendsville, Tennessee, where the Lenoir is prominently displayed, Mosheim-type limestones occur at several horizons. The lowest "Mosheim" zone, 10–35 feet thick, contains a few reddish mudrocks like those in the lower Blackford of southwestern Virginia. In the northeast environs of Friendsville, where the lower "Mosheim" zone is developed, the lower dolomitic division of the typical Lenoir is absent, and the basal calcilutite is overlain by the middle, fossiliferous division of the Lenoir. These "Mosheim" beds may be a dove limestone facies of the lower Lenoir. In the vicinity of Friends Church, in the northwestern corner of the town, "Mosheim" beds appear at two or three levels in the Lenoir, none of them at the base of the formation, which is there made by fossiliferous reefy limestone. Since the real Lenoir contains more than one intercalation of dove-gray calcilutite and since a substantial part of the lower Lenoir seems to be supplanted by this type of limestone, the writers believe the beds with "Mosheim" lithology are a facies of the typical Lenoir. Probably the type Mosheim is a calcilutite facies representing a substantial part of the true Lenoir. Certainly, usage of the name Mosheim for a pre-Lenoir stratigraphic division should not be extended hundreds of miles away from the type locality, when evidence that the Mosheim underlies the Lenoir is wholly lacking in critical localities. Even if there were a pre-Lenoir Mosheim, as Ulrich and Butts have long maintained, it could not be the *Tetradium syringoporoides* beds of Northern Virginia. This zone is equivalent to the Blackford dolomitic mudrocks which correlate with the lower division of the type Lenoir, whereas the Mosheim according to Ulrich and Butts is below the Lenoir.

The *Dinorthis atavoides* beds which Butts (1940) has identified as Lenoir in the middle and northern parts of the Shenandoah Valley and in much of southwestern Virginia appear wholly unrelated to the typical Lenoir of Tennessee. The fossils in the middle division of the real Lenoir are unknown in Butts' Lenoir of the Shenandoah Valley. Furthermore, the dinorthid and sowerbyellid brachiopods—the dominant elements in the supposed Lenoir of the Shenandoah Valley—are unknown not only in the real Lenoir but also in the New York Chazy. Although *Maclurites magnus* occurs abundantly in the upper 100–125 feet of the Lenoir and in the *Dinorthis atavoides* zone in the Shenandoah Valley, that fossil has also been reported from so many other formations that it has no index value. Although the genera *Hesperorthis*, *Valcourea*, *Camerella*, *Mimella*, and *Multicostella* are represented in the lower division of Butts' Lenoir southeast of Staunton, the species are not the same as those occurring in the New York Chazy and in the typical Lenoir of Tennessee; hence, no positive correlation with these beds can be established.

Correlatives of the real Lenoir, much the same in thickness, fauna, and lithology as the Lenoir in the Philadelphia-Lenoir City belt in Tennessee, have been identified by the writers in the Marion-Bristol sector of the Appalachian Valley in Virginia. Along U. S. Route 11 southwest of Marion, Virginia, where the three divisions of the typical Lenoir are well developed, no "Mosheim" seems to occur. However, in the abandoned stone quarry in the northeast environs of Marion, 35–40 feet of calcilutite resembling the beds at Mosheim, Tennessee, immediately overlies the Canadian dolomite. The succeeding Lenoir consists of only 8 feet of *Maclurites*-bearing limestone, which is overlain by the "Whitesburg." Possibly the "Mosheim" calcilutites in the Marion quarry represent most of the Lenoir which occurs west of the town and in the Philadelphia-Lenoir City belt in Tennessee. Although the name Lenoir might be suitable in the Marion-Bristol sector, it should not be used for the *Dinorthis atavoides* zone.

MURAT

The Murat, as originally defined by Campbell (1905, p. 445–447), included the cherty *Hesperorthis* beds, as well as the succeeding thick zone of light-gray calcarenite and associated cherty limestones with *Dinorthis atavoides*, in the general vicinity of Lexington, Rockbridge County. The *Tetradium* calcilutite at the base of the lower Middle Ordovician was probably classed by Campbell with the †Natural Bridge limestone.

Bassler identified the granular, clastic-textured, algal limestone below the *Dinorthis atavoides* zone in the northeast environs of Staunton, Augusta County, as Murat but apparently excluded the succeeding cherty beds. Butts regarded the Murat as applicable only to the coarse-grained limestone and mistakenly believed the granular beds to be younger than any part of the associated cherty limestone which was identified with the Lenior. Thus, Murat, regarded as a synonym for Holston, ceased to be used. However, as originally defined, the Murat included not only the granular beds but also the associated cherty limestones. Butts presumably was not aware that cherty limestones with *Sowerbyites triseptatus* and *Di-*

northis atavoides, which he has identified elsewhere as Lenoir, actually overlie the granular beds which he called Holston (Geologic section 40). Obviously, Holston is an inappropriate name for the granular beds because the Holston is supposed to be younger than the Lenoir. As previously indicated (Cooper, 1944, p. 59–60) Holston cannot be regarded as a time-stratigraphic name but is rather a convenient name for a characteristic facies of lower Middle Ordovician limestone in the southern Appalachian region. Thus Murat could reasonably be revived and used as a facies name for the coarse-grained calcarenites associated with the *Dinorthis atavoides* beds in the northern Appalachian region.

WHITESBURG AND ATHENS

Butts (1940, p. 159–170) has used the name Athens in Virginia for the thick body of black shale and dense black limestone below the Martinsburg in the southeastern belts of the Appalachian Valley of Virginia. Shales are most prominent near the west foot of the Blue Ridge and in some places are largely supplanted by coarse arkosic beds. The dense black limestone facies is best developed in the vicinity of Harrisonburg. The most characteristic feature of the Athens is the abundant graptolites in the shaly layers. The Whitesburg is generally regarded as occurring just below the base of the Athens, but the few feet of dark-gray calcarenitic rock generally identified as representing all the Whitesburg is faunally very similar to succeeding beds of the so-called Athens. In a well-exposed section 1.6 miles south of Bethel Church and 6 miles east of Harrisonburg (Geologic section 24), Butts' *Multicostella whitesburgensis* and "Whitesburg" forms of *Ptychoglyptus* occur 250–300 feet above the brown-weathering "trilobite beds" representing Butts, Whitesburg, and above graptolite-bearing black shales.

From the Walker Mountain belt of the Whitesburg and Athens, G. A. Cooper has collected a great variety of excellently preserved brachiopods and trilobites from the so-called Whitesburg limestone and graptolitiferous shale, in the Porterfield quarry of the Mathieson Alkali Works, near Saltville, Smyth County, Virginia. About 1.3 miles S. 30° E. of Sharon Springs, Bland County, about 30 miles northeast of Saltville in the same belt of outcrop, the writers collected many of the same fossils from Athens beds at least 250 feet stratigraphically above the dark-gray coarsely granular trilobite beds yielding fossils in the Porterfield quarry.

The type Athens is devoid of black shale and black limestone and is predominantly a calcareous siltstone or fine-grained sandstone. The type Whitesburg, composed of black limestone and intercalated graptolitiferous shales with an aggregate thickness of 500 feet, is faunally and lithologically similar to the beds identified as Athens in Virginia. Indeed the typical Whitesburg limestone near Bulls Gap, Tennessee and the limestone phase of the Athens of southwestern Virginia represent the limy equivalents of the Athens of Tennessee. Since recent work by Rodgers (Schuchert, 1943, p. 321) suggests that the Tennessee Athens grades laterally into beds identified as Lenoir, there is ample reason for postponement of usage of the Tennessee names in any part of Virginia until their precise relations in the typical areas are fully clarified.

LIBERTY HALL

Campbell (1905, p. 445–447) gave the name Liberty Hall to the thick body of limestone directly succeeding the light-gray, coarse-grained Murat limestone, in the vicinity of Lexington, Virginia. In all probability, he meant to include in the Liberty Hall limestone the basal granular layers which Butts (1940, p. 155) identified as Whitesburg.

The name Liberty Hall was abandoned (Wilmarth, 1938, p. 1179) when it was concluded that the beds were equivalent to the Athens, a prior name. It now appears that Liberty Hall should be revived, because the replacing name Athens is too restricted. The Liberty Hall undoubtedly includes beds of different ages in various parts of the northern part of the Appalachian Valley of Virginia. To have any enduring standing as a stratigraphic name, Liberty Hall should be used only as the name for a characteristic facies, and not as a name for a definite time-stratigraphic unit.

CHAMBERSBURG AND LOWVILLE

The name Chambersburg, as now generally used, applies to a formation of limestone believed to be above the Lowville and below the *Sinuites* beds at the base of the Martinsburg shale. It includes, in ascending order, the lower *Echinosphaerites*, *Nidulites-Lambeophyllum*, and *Christiania* [*Bimuria*] zones, and also the so-called Greencastle beds of Bassler (1919, p. 131, 143–144). The *Tetradium cellulosum* beds, originally classed as the basal member of the type Chambersburg by Stose (1909), are now regarded as a separate formation, supposedly the Lowville (Butts and others, 1932, p. 16).

The 150 feet of limestone with *Tetradium cellulosum*, identified as Lowville by Stose, Ulrich, and later Butts, is faunally and lithologically inseparable from the underlying 200-foot succession of calcilutite which also contains this fossil. Since the 358 feet of *Tetradium* beds near Marion, Pennsylvania, is dissimilar in appearance and fossils to the succeeding Chambersburg, Butts' emendation of the original Chambersburg is adequately justified. However, positive identification of the *Tetradium cellulosum* beds as New York Lowville seems unjustified although they are undoubtedly of Black River age. This zone is not the same as the so-called Lowville identified by Stose and Ulrich at Fort Loudon, Dickey, and St. Thomas, Pennsylvania.

Geologic section 6.—Emended Chambersburg formation in the type locality, 2 miles southwest of Marion, Pennsylvania

	Thickness Feet
Martinsburg shale	
Chambersburg limestone (749 feet)	
Reuschella "edsoni" beds	
10. Limestone, argillaceous, cobbly weathering; contains intercalated silty layers and thin beds of coarsely granular limestone. Fossils include *Lingulasma* sp., *"Leptobolus" ovalis* Bassler, *"Sowerbyella" pisum* (Ruedemann), *Christiania trentonensis* Ruedemann, *Bimuria lamellosa* (Bassler), and *Echinosphaerites aurantium* (Gyllenhahl)	60

	Thickness Feet
Nidulites beds	
9. Limestone, cobbly, argillaceous, dark gray	58
8. Limestone, black dense, slabby; clayey partings and thin silty layers near the top	122
7. Limestone, dark gray to black, fine-grained, dense, relatively even-bedded	164
6. Limestone, nodular, dark gray, impure; contains *Caryocystites*	29
5. Limestone, dark gray to black, weathers cobbly; contains thin buff-weathering partings of clay; *Nidulites*	70
4. Limestone, gray, argillaceous, weathers nodular	38
3. Limestone, black, fine-grained, slabby; contains *Nidulites*	46
Lower *Echinosphaerites* beds	
2. Limestone, cobbly, very argillaceous, with partings of buff metabentonitic clay near the top; contains *Oxoplecia* sp., *Dinorthis* cf. *D. transversa* Willard, *Corineorthis*, *Schizambon* sp., *Resserella* cf. R. *rogata* (Sardeson), *Calliops* cf. *C. annulatus* (Raymond), *Bumastus* sp., *Chasmatopora* sp., and *Echinosphaerites*	130
1. Limestone, dark gray, granular, sparsely cherty; contains *Dinorthis transversa* and *Oxoplecia*	32
Stose's Lowville limestone.....150 feet } units 10 to 16 of Geologic section 4	358
Upper division of Stose's "Stones River" limestone..208 feet }	

Geologic section 7.—Chambersburg limestone 2.6 miles S. 12° W. of St. Thomas, Franklin County, Pennsylvania

	Thickness Feet
Martinsburg shale	
Chambersburg limestone (225 feet)	
8. Limestone, coarse-grained, gray, clayey partings; "*Leptololus ovalis*"	8–10
7. Limestone, black, fine-grained, irregularly bedded, contains *Receptaculites* cf. *R. occidentalis* Billings	22
6. Limestone, dark gray, fine- to medium-grained, weathers cobbly	44
5. Limestone, dark gray, impure; contains intercalated beds of pebble conglomerate and calcarenite; *Cryptophragmus antiquatus* Raymond occurs near the top	17
4. Limestone, dark gray; granular calcarenite at top contains *Caryocystites*; lower beds contain *Nidulites*	28
3. Limestone, black, cobbly, largely covered	82
2. Limestone, dark gray, fine-grained, only partly exposed in road ditches; contains *Nidulites*	22
"Stones River" limestone	
1. Calcilutite, dove gray; contains impure magnesian layers; base not exposed	50+

Ulrich (1911, p. 325) correlated the 150 feet of dove-gray *Tetradium cellulosum*-bearing calcilutite, which Stose made the basal (Lowville) division of the type Chambersburg, with the *Cryptophragmus*-bearing limestone above the horizon of *Caryocystites* in the Mercersburg quadrangle (unit 5, Geologic section 7). As shown in Figure 3, this correlation seems to be in error. Because *Caryocystites* occurs in the *Nidulites-Lambeophyllum* zone of both the St. Thomas and the type Chambersburg sections, it is most reasonable to regard the occurrences as at approximately the same horizon. Since the *Tetradium cellulosum* beds originally classed with the type Chambersburg are more than 300 feet below the horizon of *Caryocystites*, it is very unlikely that they are equivalent to the *Cryptophragmus*-bearing limestone occurring above the horizon of *Caryocystites* in the section near St. Thomas.

As previously mentioned, Ulrich (Stose, 1909, p. 7) has identified many typical Black River fossils from the *Tetradium cellulosum* beds originally classed with the

Chambersburg, namely: *Orbignyella wetherbyi*, *Strophomena* cf. *S. emaciata*, *Zygospira recurvirostris*, *Protorhyncha* sp., *Leperditia* cf. *L. fabulites*, *Leperditella tumida*, *Isotelus* sp., *Calliops callicephalus*, *Ceraurus pleurexanthemus*, and *Tetradium cellulosum*. None of these, except *Leperditia fabulites*, has ever been cited from beds

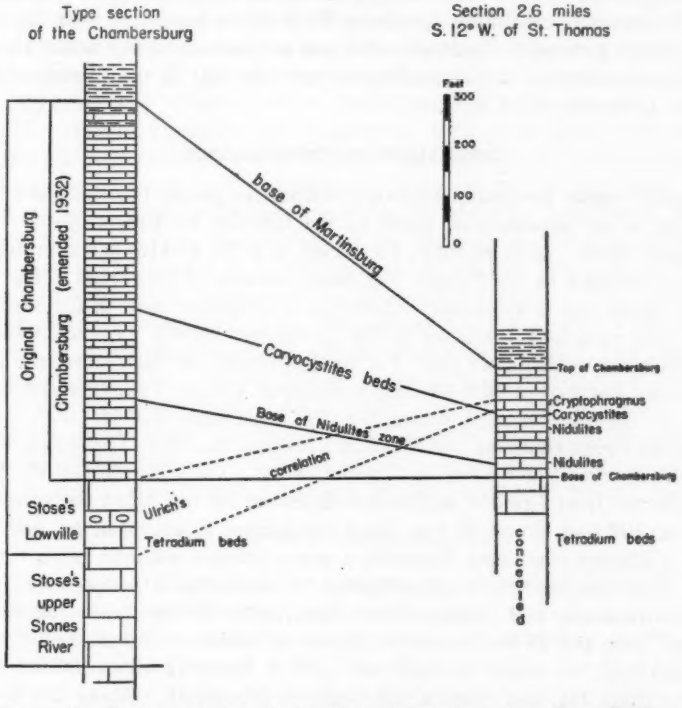

FIGURE 1.—*Positions of supposed Lowville equivalents in southern Pennsylvania*

older than Black River. At present, the thick zone with *Tetradium cellulosum*, which occurs below the type Chambersburg, should be regarded as wholly or in part equivalent to the Pamelia and Lowville formations of the Black River group of New York. The beds with *Cryptophragmus*, at Dickey, Fort Loudon, and near St. Thomas, Pennsylvania, would necessarily by younger than the *Tetradium cellulosum* beds of the section near Marion, Pennsylvania. The above-mentioned sections show beyond reasonable doubt that *Cryptophragmus antiquatus* and *Tetradium cellulosum* do not necessarily signify the same stratigraphic zone, or any zone in particular as previously supposed (Butts, 1928, p. 365).

In Virginia, the Chambersburg limestone is supposed to be younger than the Lowville (Butts, 1940, p. 195) and together with the Eggleston formation is regarded as representative of the late Black River (Leray of Chaumont) of New York. In parts of Shenandoah and Rockingham counties, Virginia, *Cryptophragmus antiquatus*

occurs rather abundantly 20–75 feet below the *Reuschella edsoni* zone—in essentially the same position as at Dickey, Fort Loudon, and St. Thomas, Pennsylvania. These occurrences indicate that the Chambersburg either includes the Lowville and Pamelia or *Cryptophragmus* is not confined to these beds. In deliberating these alternatives, it should be remembered that the type section of the Chambersburg is underlain by a succession of calcilutites containing Black River fossils and that the position of this thick zone with *Tetradium cellulosum* is hundreds of feet below the rather abundant occurrences of *Cryptophragmus* near the top of the Chambersburg, as seen in numerous other sections.

INDEX VALUE OF CRYPTOPHRAGMUS

Cryptophragmus antiquatus Raymond (=*Beatricea gracilis* Foerste) has long been regarded as an unmistakable guide to the Lowville by Ulrich, Butts (1928, p. 365), and others. More recently, Kay (1944, p. 1–23, 97–116) has interpreted this fossil as an index to the Pamelia and basal Lowville of New York. The first of several discoveries of anomalous occurrences of *Cryptophragmus* in the Shenandoah Valley was made by Edmundson during the summer of 1942. The fossil was found with *Nidulites* in the upper part of a thick succession of black limestones exposed in the west environs of New Market, Shenandoah County. Another specimen was found at the same locality, during the field conference of 1944.

Another *Cryptophragmus* was found in a section near State Highway 274, about 1.7 miles southwest of Wadesville, Clarke County. The specimen (*see* Pl. 2, fig. 2) was collected from a cobbly, argillaceous limestone 230 feet below the lowest occurrence of *Nidulites*, about 35 feet above the highest *Echinosphaerites*, and 20 feet below a siltstone containing *Resserella*, a genus hitherto unknown below the Rockland. Four specimens of *Cryptophragmus*, in association with species of *Camarocladia*, *Helicotoma*, and *Subulites*, were found about 50 feet below the *Reuschella "edsoni"* zone and 25 feet above the highest occurrence of *Nidulites* on the M. M. Bowman farm, one-fourth of a mile east of U. S. Route 11, about 500 feet north of County Road 721, and about a mile south of Woodstock. About 200 feet lower in the section another specimen occurs on the same slab with abundant *Nidulites* (Geologic section 21). Several excellent specimens of *Cryptophragmus* were found in dove-colored limestone, possibly 75 feet above the top of the *Nidulites* zone and about 30 feet below the *Reuschella "edsoni"* zone, 300 feet west of the intersection of Roads 691 and 692, about 3.5 miles N. 70° W. of Edinburg, Shenandoah County. A dozen or more specimens of *Cryptophragmus* occur in thin partings of calcarenite intercalated in dense black limestone 20–60 feet below the base of the *Reuschella "edsoni"* zone, 1.5 miles north of Edinburg (Geologic section 11); at Cedar Grove Church about 3.7 miles south of Mt. Jackson (Geologic section 22), and in the fields just north of Road 753, about 0.4 mile west of Linville Station. Another excellent specimen (*See* Pl. 2, fig. 1), occurring in a bed containing *Lambeophyllum* and *Nidulites*, was collected from typical cobbly Chambersburg limestone about 800 feet N. 80° W. of the intersection of Roads 691 and 694, about 2.5 miles west of Lantz Mills, Shenandoah County. Hence, forms of *Cryptophragmus* indistinguishable

from *C. antiquatus* range through several hundred feet of beds and are most common between the *Nidulites* and *Reuschella* zones of the Chambersburg. The Pamelia and lower Lowville occurrences of this fossil may come within the range of *Cryptophragmus*, as recently determined in the Shenandoah Valley, but, since Black River fossils occur below the type Chambersburg, the Pamelia equivalents, if present, must range below the base of the Chambersburg. Okulitch (1939, p. 319–339) records *Cryptophragmus* from beds as old as the Pamelia and as young as the Coboconk limestone, which he interprets as upper Black River, but which Kay (1937, p. 256–257) believes to be early Trenton (Rockland).

The above-stated occurrences and relationships of *Cryptophragmus*, with respect to the lower Middle Ordovician beds in the Shenandoah Valley, demonstrate that *Cryptophragmus antiquatus* is not restricted to a narrow stratigraphic zone. Considerable basis exists for tentatively regarding the abundant occurrences of this fossil near the top of the Chambersburg of the Shenandoah Valley as essentially the same age as the horizon of *Cryptophragmus* in the high Black River Witten limestone of southwestern Virginia and the Lebanon limestone of central Tennessee. In all three areas, *Camarocladia* is an invariable associate of *Cryptophragmus*, and a profusion of gastropods, mainly referable to *Helicotoma*, *Subulites*, and *Omospira* occurs in the same beds. Also, the Witten occurrences of *Cryptophragmus* are not far above the beds with *Foerstephyllum "halli"* (Cooper, 1944, p. 83–92). This coral and the characteristic brachiopod *Doleroides* occur just below the beds with abundant *Cryptophragmus* a few miles northwest of Edinburg (Geologic section 12) and also in the Wardell formation beneath the Witten of southwestern Virginia.

INDEX VALUE OF NIDULITES PYRIFORMIS

In the Shenandoah Valley, *Nidulites pyriformis* is regarded by Butts (1940, p. 200–201) as ". . .the most important fossil for the identification of the Chambersburg." The genus *Nidulites* makes its appearance in the form of *N. ovoides* Butts in the *Dinorthis atavoides* zone of Virginia (Geologic section 27). *Nidulites pyriformis* is very common in the Ward Cove limestone of Tazewell County, Virginia, which was formerly regarded as lower Ottosee (Butts, 1940, p. 170–178). It has also been seen in the upper part of the "Athens" along Walker Mountain (Cooper, 1944, p. 66–68).

The range of *Nidulites pyriformis* in the Chambersburg is well shown in the section along U. S. Route 40, about 7 miles west of Hagerstown, Maryland.

Geologic section 8.—Chambersburg limestone along U. S. Route 40 near Wilson, about 7 miles west of Hagerstown, Maryland

	Thickness Feet	Thickness Inches
Section begins at west end of highway bridge across Conococheague Creek		
Chambersburg limestone (316 feet)		
16. Limestone, cobbly, somewhat granular; upper part of zone probably in contact with the basal Martinsburg, but not exposed; contains *Christiania* and *"Sowerbyella" pisum* (Ruedemann)	53+	
15. Limestone, cobbly, black	15	
14. Metabentonite		8

	Thickness Feet	Inches
13. Limestone, fine-grained, cobbly	12	
12. Siltstone, shaly, buff	1	
11. Metabentonite		2–4
10. Chert	3	
9. Limestone, fine-grained, black, cobbly	9	
8. Metabentonite, buff		2–4
7. Limestone, black, shaly streaks, cobbly; contains a few *Nidulites pyriformis*	17	
6. Limestone, thick-bedded, contains gastropods and *Camarocladia* and a few *Nidulites pyriformis*	50	
5. Limestone, black, slabby to cobbly; *Nidulites* abundant	30	
4. Limestone, black, thick-bedded	13	
3. Limestone, black, slabby; *Nidulites* abundant	54	
2. Limestone, very cobbly; contains many partings of buff clay; a large *Corineorthis* 14 feet below the top, a layer crowded with *Echinosphaerites* 11 feet lower, and *Nidulites pyriformis* to within 10 feet of the base	71	
Pre-Chambersburg, post-Beekmantown limestone		
1. Calcilutite, with intercalated impure layers; contains *Tetradium cellulosum* and *Leperditia fabulites*; described in detail in Geologic section 5)	—	

Here, as in the Shenandoah Valley of Virginia, *Nidulites pyriformis* occurs sparsely in the limestones not far below the *Christiania* or *Rueschella "edsoni"* zone and abundantly in the middle part of the formation. Its occurrence in the lower *Echinosphaerites* zone is relatively sparse, and in a casual search for fossils it is apt to be missed. *Nidulites* has not been seen in Virginia in the granular beds containing abundant *Cryptophragmus*, or in succeeding beds.

Nidulites seems to characterize a certain peculiar variety of Middle Ordovician limestone which is finely granular, thin-bedded, and weathers smoke gray. In these beds, as at Vaucluse (Geologic section 16), *Nidulites* occurs in great profusion. It is generally sparse in cobbly beds, for example, at Wilson, Maryland, and in the well-exposed section 4.6 miles N. 69° W. of Edinburg, Shenandoah County. It is even rarer in dense black limestones, such as are so prominent in the vicinity of Harrisonburg. It occurs in this kind of limestone about 30 feet below the *Reuschella "edsoni"* beds about half a mile east of Lacey Spring Post Office and in about the same position a quarter of a mile west of the intersection of State Highway 260 and Road 767, 2.8 miles N. 8° W. of Harrisonburg. Like the genus *Tetradium* found in nearly all Middle Ordovician calcilutites and like *Cryptophragmus* which often occurs in shell limestone or coarse calcarenite, *Nidulites pyriformis* is a "facies fossil" which is to be expected anywhere within the interval between the *Dinorthis atavoides* beds and the *Reuschella* zone. Its absence or presence at various horizons within this interval was very probably determined by depositional conditions, which changed locally from time to time. That *Nidulites pyriformis* is also a facies fossil in the Ward Cove limestone of southwestern Virginia has been previously recorded (Cooper and Prouty, 1943, p. 829–830).

RANGE OF NORMANSKILL GRAPTOLITES

The graptolites in the Middle Ordovician of the Shenandoah Valley are likewise facies fossils. Abundant occurrences are confined to black shale or platy argillaceous

limestone. These graptolites are undoubtedly like those in the Normanskill shale of New York (Ruedemann, 1901; 1930, p. 96–104; Powell, 1915, p. 272–281; Butts, 1940, p. 166–170).

At least two principal zones of graptolites occur in the Normanskill shale (Ruedemann, 1930, p. 101–103). The lower zone is characterized by *Nemagraptus gracilis* and a relatively large number of genera, species, and individuals. The upper zone of the Normanskill lacks *Nemagraptus* and many of its associates. The upper zone contains notably fewer species and individuals of the genera *Didymograptus*, *Dicellograptus*, and *Dicranograptus*, and it is characterized by *Diplograptus foliaceus*, *Climacograptus scharenbergi*, *C. bicornis*, and locally in the Albany district (Ruedemann, 1930, p. 103) by *Corynoides gracilis*.

Butts (1940, p. 167) has correlated all the Virginia Athens with the *Nemagraptus gracilis* zone of the Normanskill, but there is evidence opposing this view. Nowhere in the Shenandoah Valley is the *Nemagraptus* fauna known to occur high in the so-called Athens. As well shown in the upper "Athens" exposed along U. S. Route 33 about 5 miles southeast of Harrisonburg, *Climacograptus* and *Diplograptus*, with possibly a few *Dicellograptus*, are the only graptolites which occur. There is every reason to believe that the upper "Athens" as exhibited there and elsewhere in northern Virginia corresponds to the upper graptolite zone of the Normanskill shale as developed in New York and in the province of Quebec, Canada.

It should also be mentioned that a large *Climacograptus* occurs in a silty zone intercalated in the *Nidulites* beds near Wadesville, Clarke County, Virginia (Geologic section 17). Another occurrence of the Diplograptidae was noted in the thick, dense, black limestone about 60 feet below the *Reuschella "edsoni"* beds in the section 0.5 mile east of Lacey Spring Post Office. In both instances, the containing beds have been identified by Butts as Chambersburg, although the presence of these graptolites was unknown to him.

Of even greater interest is the fact that Ruedemann (1930, p. 106–107) has identified Normanskill-Athens species of graptolites from the group of limestone pebbles in the Rysedorph conglomerate, which, as is widely agreed, contains many characteristic Chambersburg fossils. The Rysedorph conglomerate itself is Trenton in age, but the parent sediments from which its pebbles were derived range from Cambrian to Trenton (Ruedemann, 1930, p. 106). In the Rysedorph, the dense black limestone pebbles containing *Climacograptus scharenbergi* and *Diplograptus foliaceus* and numerous Chambersburg fossils must have come from a parent sediment correlative with a part of the Normanskill shale, as indicated by the above-named Normanskill graptolites. It is not unlikely that the graptolites occasionally seen with *Nidulites pyriformis* in Butts' Chambersburg correlate with the upper graptolite zone of the Normanskill. Thus the greater part of the Chambersburg as well as much of the "Athens" of the Shenandoah Valley is probably represented in the Normanskill.

Objection to this tentative conclusion might be made on the grounds that the Normanskill is Chazyan and that the Chambersburg is undoubtedly Black River. The post-Chazyan age of the Chambersburg is indicated by several lines of evidence, but there is no longer any reason to regard the Normanskill as Chazyan. Originally, Ruedemann (1901, p. 551; 1908, p. 10–29) put the Normanskill in the Trenton.

Ulrich (1911, p. 512) believed it to be between the Lowville and Chazy. Raymond (1916) and later Ulrich (1930, p. 73) and Butts (1928; 1933; 1940; Butts and others 1932) placed it in the upper Chazyan. The basis for this assignment was that the so-called Athens in Virginia underlies beds containing *Cryptophragmus* and identified by Ulrich and Butts as Lowville. The basis for the identification of these beds as Lowville can now be challenged. Supposed Lowville beds with *Tetradium cellulosum* and other Black River fossils were excluded from the type Chambersburg by Butts and made a separate, lower formation. *Cryptophragmus antiquatus*, likewise regarded a valid guide to the Lowville, is now known in the upper Chambersburg, a facies of the "Athens" of Virginia. Thus the zone with abundant *Cryptophragmus* in Virginia may not be Lowville, but considerably younger than that formation. It can no longer be assumed that all Appalachian formations below the supposed Lowville are necessarily Chazyan or older.

WHITESBURG-ATHENS-CHAMBERSBURG RELATIONS

That much of the Chambersburg, as identified by Butts along Tumbling Run near Strasburg, is laterally continuous with the greater part of the Whitesburg-Athens succession of the Harrisonburg area is indicated by several lines of evidence.

The lower 75 feet of the Chambersburg, near Strasburg Junction, which is faunally and lithologically linked with the lower part of the type Chambersburg (unit 2, Geologic section 6), contains a "Whitesburg" fauna of bryozoans, brachiopods, and trilobites. The trilobite genera *Robergia*, *Bronteopsis*, and *Arthrorhachis*, which occur in the lower 45 feet of the *Nidulites* beds of the Tumbling Run section are also generally regarded as characteristic of the Athens and Whitesburg (Butts, 1940, p. 158). The faunal similarities of the lower *Echinosphaerites* zone and *Nidulites* beds to the Virginia Athens and Whitesburg are summarized in Table 1.

In the belt of outcrop immediately west of Massanutten Mountain between Winchester and Lacey Spring, interbedding of the characteristic "Athens" type of dense black limestone with the typically cobbly Chambersburg can be observed in many places. About 200 yards east of U. S. Route 11, just north of Vaucluse, Frederick County, 256 feet of beds, representing much of the *Nidulites-Lambeophyllum* zone, is very suggestive of "Athens" (Geologic section 16). To a somewhat lesser extent, the same is true of the *Nidulites-Lambeophyllum* zone exposed along Tumbling Run southwest of Strasburg (Geologic section 20). Just west of Cedar Grove Church, 1000 feet east of U. S. Route 11 and 3.7 miles south of Mt. Jackson, Shenandoah County, even-bedded dense black limestones, many with the characteristic linear series of pits on weathered surfaces, occur above *Nidulites*-bearing beds which Butts considers Chambersburg. Not more than 50 feet below the *Reuschella "edsoni"* zone, about 1000 feet east of Lacey Spring, thick beds of dense black limestone of "Athens" type contains *Nidulites pyriformis*, which is supposed to be a Chambersburg guide fossil, and poorly preserved diplograptids.

On the east side of the Massanutten syncline, the interfingering of the Athens and Chambersburg is less evident because of poor exposures, but 1.7 miles southwest of Wadesville, about 650 feet south of State Highway 274, the intertonguing relations are well shown (Geologic section 17). The Martinsburg shale is under-

TABLE 1.—*Fossils occurring in Butts's Chambersburg, Athens, and Whitesburg formations in Virginia*

FOSSILS b = reported by Butts c = reported by the writers x = listed by both sources	lower *Echinosphaerites* and *Nidulites* zones (Chambersburg)	"Athens" formation	"Whitesburg" limestone
SPONGES			
Nidulites pyriformis Bassler (Pl. 2, figs. 3–4)	x	c	
Receptaculites sp.	x	x	x
BRYOZOANS			
Chasmatopora and related genera	x	c	x
Glauconome sp.	x		x
Mesotrypa sp.	x		x
Pachydictya sp.	b		b
Rhinidictya sp.	x	c	x
CYSTOIDS			
Echinosphaerites aurantium Gyllenhahl	x	c	x
BRACHIOPODS			
Christiania trentonensis Ruedemann	x	c	c
Cyclospira sp.	c	c	
Cyrtonotella sp. (Pl. 3, figs. 19–20)	c	c	c
Corineorthis sp. (Pl. 3, figs. 13–15)	c	c	c
Dinorthis transversa Willard (Pl. 2, figs. 10–11)	c	c	
Dinorthis cf. *D. pectinella* (Emmons)	b		b
Leptellina, same or very similar species	x	c	c
Leptobolus sp.	x	b	x
Lingula cf. *L. nympha* Raymond (not Billings) (Pl. 2, figs. 12–13)	b	x	
Multicostella bursa (Raymond) = *M. whitesburgensis* Butts (Pl. 2, figs. 7–8	c	c	x
Opikina "minnesotensis" (Winchell)	x	c	x
Orbiculoidea sp.	b	b	b
Oxoplecia cf. *O. simulatrix* (Bassler) (Pl. 3, figs. 16–18)	x	c	c
Protozyga sp.	c	c	
Ptychoglyptus virginiensis Willard (Pl. 3, figs. 24–25)	c	x	x
Resserella cf. *R. rogata* (Sardeson) (Pl. 2, figs. 14–15)	c	c	c
Schizambon sp.	x	x	x
Sowerbyella negrita (Raymond)	c	c	c
Sowerbyella sp.	x	x	x
TRILOBITES			
Arthrorhachis elspethi Raymond (Pl. 3, figs. 3–6)	x	x	x
Ampyx hastatus Ruedemann	x	c	c
Ampyxina sp.	c	x	x
Bronteopsis gregaria Raymond (Pl. 3, figs. 1–2)	x	x	x
Bumastus sp.	c	c	c
Calliops annulatus (Raymond)	c	c	x
Ceraurus pleurexanthemus Green (Pl. 3, figs. 7–8)	c		c
Cryptolithus sp.	c	c	c

TABLE 1—*Continued*

FOSSILS b = reported by Butts c = reported by the writers x = listed by both sources	lower *Echinosphaerites* and *Nidulites* zones (Chambersburg)	"Athens" formation	"Whitesburg" limestone
TRILOBITES—*Continued*			
Dionide holdeni Raymond (Pl. 3, figs. 9–10)	c	x	x
Eoharpes sp.	c		b
Lonchodomas sp.	x	x	
Remopleurides sp.	c	b	
Robergia sp.	c	x	x
Sphaerexochus sp.	b		b
Sphaerocoryphe major Ruedemann	c		c
Tretaspis reticulata Ruedemann	x	x	c

lain, in descending stratigraphic order, by 136 feet of *Nidulites*-bearing cobbly limestone and intercalated silty beds; 125 feet of dense black slabby limestone of "Athens" type, containing *Homotelus* and *Lonchodomas;* 35 feet of cobbly Chambersburg-type limestone; 46 feet of dense black "Athens" type limestone; a few feet of shaly siltstone crowded with *Resserella* cf. *R. rogata* (Sardeson); 47 feet of cobbly Chambersburg-type limestone with *Echinosphaerites aurantium* at the base; and 150 feet or so of dense black limestone extending down to the coarse-grained *Girvanella*-bearing limestone which Butts identified as Lenoir.

In the vicinity of Harrisonburg, where the so-called Athens is well developed, fossils are exceedingly scarce, and the same is true for all the intercalated beds of "Athens" type occurring in Butts' Chambersburg of northern Virginia.

The beds above the *Dinorthis atavoides* zone and below the *Reuschella "edsoni"* beds show great variation in both lithology and thickness between Harrisonburg and the northern end of the Shenandoah Valley. The "Chambersburg" in the belts west of Lantz Mills, Shenandoah County, is almost entirely cobbly, buff-weathering beds with few, if any, layers resembling the dense black limestone of the "Athens." The latter type of beds predominates almost to the exclusion of cobbly "Chambersburg" layers near Harrisonburg. Gradations between these two contrasting but essentially equivalent facies of limestone can be observed in many sections in the same belt of outcrop between Mt. Jackson, Shenandoah County, Virginia, and Chambersburg, Franklin County, Pennsylvania.

In summary, the postulated equivalency of most of the "Whitesburg" and "Athens", as developed near Harrisonburg, to the Chambersburg of northern Virginia is supported by (1) dove-tailing relations of two distinctive and characteristic lithologies, and (2) similar and identical faunal elements in the two dissimilar facies. The greater thickness of "Whitesburg-Athens" near Harrisonburg probably reflects a faster rate of deposition than prevailed where the typically cobbly Chambersburg limestone accumulated.

At this point, it is advisable to consider the salient objections to this interpretation.

It might be argued, on the basis of apparently well established evidence, that the Athens and the Chambersburg could not be equivalent because the Athens and the equivalent Normanskill are Chazyan and that the Chambersburg, being defined as post-Lowville, is late Black River and possibly early Trenton. The Normanskill shale does not occur in either the type Chazy limestone or in the type Black River, and its supposed Chazyan age rests upon the assumption that its equivalent—the Virginia Athens—is Chazyan. As previously mentioned, the fact that the Virginia Athens underlies Butts' Lowville does not necessarily mean that it is Chazyan. Indeed, if the Lowville were to be recognized on the basis of the common occurrence of *Cryptophragmus antiquatus*, the formation would have to be placed above the *Nidulites-Lambeophyllum* and lower *Echinosphaerites* zones of the Virginia Chambersburg and not below the Chambersburg as previously determined by Stose, Ulrich, Butts, and others.

Another possible objection which might be raised is that the siltstone at or near the base of the Chambersburg between Maurertown, Shenandoah County, and Winchester, Frederick County, occurs above the "Athens" in the section 1.7 miles southwest of Wadesville, Clarke County, and therefore proves that the Chambersburg is younger than the Athens. The Wadesville section exhibits two distinctly silty zones. The upper one, which is 35 feet thick and contains intercalated impure limestones (Geologic section 17, unit 15), could not be correlated with the siltstone at the base of the Chambersburg along Tumbling Run, because it is underlain by 20 feet of *Nidulites* beds, whereas, on Tumbling Run, the base of the *Nidulites* zone is at least 65 feet above the siltstone. Also the lower *Echinosphaerites* bed in the Wadesville section is 280 feet below the upper siltstone, whereas in the Tumbling Run section the lower *Echinosphaerites* zone directly succeeds it. The lower siltstone of the Wadesville section cannot be correlated with the silty bed west of Strasburg, because the lowest occurrences of *Cryptophragmus* and *Echinosphaerites* come above the horizon of the siltstone west of Strasburg. These two fossils occur below the lower siltstone of the Wadesville section.

Along U. S. Route 33 about 5 miles southeast of Harrisonburg, a shaly-weathering siltstone, very similar to the lower silty bed of the Wadesville section and likewise containing *Resserella* cf. *R. rogata* (Sardeson), is intercalated in a thick succession of black limestone and shale containing Normanskill graptolites (Geologic section 28) and identified as Athens. This occurrence is not cited as evidence that the lower silty bed near Wadesville is the same as the "Athens" siltstone, although they may possibly be equivalent. Of more importance is the fact that siltstones similar to those occurring in Butts' Chambersburg of northern Virginia occur also in beds which he has identified as Athens.

It may be argued that the occurrence of *Nidulites* above the thick body of black limestone and shale, near Harrisonburg, shows that the *Nidulites* beds of the Chambersburg are younger than the Athens. The apparent absence of the graptolite fauna from the cobbly Chambersburg beds would seem to support this objection. However, if the "Athens" and Chambersburg are equivalent facies, it is expectable that major elements of their respective faunas would not occur in both facies. In other words, environmental conditions favorable for burial and preservation of

graptolites may not have prevailed in other sections of the sea bottom where "Chambersburg" sedimentation was taking place. That the "Athens" graptolites are facies fossils is clearly shown by their almost exclusive occurrence in the black-shale parvafacies of the "Athens." It is likely that graptolites, which are exceedingly rare in the thick "Athens" limestones, would be even rarer in a facies lacking all the essential characteristics of the "Athens."

Nidulites pyriformis is not confined to the Chambersburg or, more particularly, to the thin zone which overlies Butts' Athens in the vicinity of Harrisonburg. Its occurrence in the "Athens" of southwestern Virginia has been previously noted by the senior writer (B. N. Cooper, 1944, p. 67–68). In northern Virginia, *Nidulites pyriformis* also occurs below the top of the "Athens." West of Cedar Grove Church, south of Mt. Jackson, Shenandoah County, this fossil occurs below 25–50 feet of beds of undoubted "Athens" lithology. The *Nidulites* beds just below the *Reuschella edsoni* zone 1000 feet east of Lacey Spring are also of "Athens" type and contain poorly preserved graptolites. Near Vaucluse, Frederick County, *Nidulites* and *Lambeophyllum* occur in a 256-foot zone much like "Athens" limestone, which is intercalated in nodular to cobbly limestones identified as Chambersburg (Geologic section 16, unit 8). The general rarity of *Nidulites* in the "Athens" may reasonably be interpreted as an indication that it, too, is a facies fossil. The equivalence of two facies cannot be established by pondering their faunal dissimilarities. The cosmopolitan, rather than the provincial, facies elements of a fauna have the greater correlative value.

Without doubt, the section best exhibiting the obvious interfingering of the so-called Athens and Chambersburg is along State Highway 251 about 2 miles east of Collierstown Post Office and 6.5 miles S. 80° W. of Lexington, Rockbridge County (Geologic section 42). The "contact" of the Athens and Chambersburg, determined by Butts (1940, Pl. 32A), is of special interest because of the occurrence of characteristic Chambersburg fossils and Chambersburg cobbly limestone within the body of black limestone identified by Butts as Athens. Actually, the lower part of the supposed Athens is more like the Chambersburg than typical Athens. *Homotelus* cf. *H. simplex*, abundant in the lower Chambersburg along Tumbling Run, near Strasburg, Shenandoah County, is very abundant in the lower 100 feet of the succession identified by Butts as Athens in the Collierstown section. *Resserella* and *Sowerbyella*, common in the typical Chambersburg of northern Virginia, are common in the lower part of the beds identified as Athens. *Bronteopsis*, cited by Butts as a characteristic Athens and Whitesburg trilobite, occurs in cobbly limestone a few feet above the Chambersburg-Athens contact as determined by Butts. The characteristic Chambersburg-Ottosee fossil, *Dinorthis transversa*, occurs not only in the cobbly beds above the base of Butts' Chambersburg of the Collierstown section but also in the upper 15 feet of Butts' Athens and in cobbly limestone below the main body of dense black "Athens" limestone.

RELATION OF THE CHAMBERSBURG AND OTTOSEE

Southwest of Roanoke, particularly in the belt along the northwest base of Walker Mountain in Bland and Smyth counties, the "Athens" is succeeded by a limestone

identified by Butts (1940, p. 170–178) as Ottosee, which according to him is pre-Lowville. The beds identified as Ottosee along Walker Mountain are faunally similar to a richly fossiliferous limestone occurring along the northwest base of Clinch Mountain in southwestern Virginia and eastern Tennessee, which has also been called Ottosee by Butts. In Tazewell and Russell counties of southwestern Virginia, the writers have collected from the Clinch Mountain belt of Ottosee a surprisingly large number of fossils which were also collected from the lower *Echinosphaerites* zone of the Chambersburg exposed near Strasburg. These fossils include:

Cystoids
- *Echinosphaerites aurantium* (Gyllenhahl)
- *Platycystites faberi* Miller

Sponges
- *Dystactospongia* sp.
- *Receptaculites* cf. *R. occidentalis* Billings

Corals
- *Lambeophyllum profundum* (Conrad)

Bryozoans
- *Anolotichia* cf. *A. explanata* Coryell
- *Chasmatopora* and related, undescribed genera
- *Scenellopora* sp.

Brachiopods
- *Corineorthis* sp.
- *Cyrtonotella* sp.
- *Dinorthis transversa* Willard
- *Leptellina* sp.
- *Multicostella* sp.
- *Opikina "minnesotensis"* (Winchell)
- *Orthambonites* sp.
- *Oxoplecia* aff. *O. simulatrix* (Bassler)
- *Ptychoglyptus* cf. *P. virginiensis* Willard
- *Resserella* cf. *R. rogata* (Sardeson)
- *Sowerbyella* sp.

Trilobites
- *Eoharpes* sp.
- *Homotelus* sp.
- *Sphaerocoryphe* sp.

As shown in Table 1, many of these fossils occur also in the Athens-Whitesburg of Virginia. Examining further the possible relationships of the Chambersburg to the Virginia Ottosee, the upper Ottosee, or Wardell, formation of southwestern Virginia (Cooper and Prouty, 1943, p. 873–875) contains *Foerstephyllum "halli"* (Nicholson), a species of *Cleiocrinus*, and *Stromatocerium rugosum* Hall. Also, the lower occurrence of *Cryptophragmus* in southwestern Virginia is between the lower and upper Ottosee. All these fossils are found in the Chambersburg of Pennsylvania. Some 60 feet or so above the top of the Wardell, *Cryptophragmus* occurs abundantly in the Witten limestone of Lebanon age (B. N. Cooper, 1945, p. 272–273), which Butts called Lowville. It is interesting to note that this fossil is most common in the post-*Nidulites* beds of the Chambersburg in the Shenandoah Valley. In parts of Russell and Tazewell counties of southwestern Virginia, the lower part of Butts' Ottosee contains abundant *Nidulites pyriformis*. The associates of this fossil—including species of *Leptellina* and *Orthambonites, Oxoplecia* aff. *O. simulatrix, Sowerbyella negrita, Hyboaspis* sp., and *Calliops annulatus*—link these beds with the "Whitesburg-Athens" limestones of the Walker Mountain belt and also with the lower Chambersburg near Strasburg, Virginia.

In summary, the Chambersburg seems to be equivalent not only to the "Whitesburg" and "Athens" as recognized in the Harrisonburg area, but to Butts' Whitesburg-Athens-Ottosee-Lowville succession in southwestern Virginia. The relationships of the Virginia Chambersburg to other formations recognized in the State are shown in Figure 2. Thus interpreted, the Virginia Athens is a megafacies of the lower Middle Ordovician which is laterally continuous with a body of limestone identified

FIGURE 2.—*Facies equivalents of the "Athens" in the Appalachian Valley of Virginia*

as Chambersburg in northern Virginia and Whitesburg, Athens, Ottosee, and Lowville, or "lower Moccasin," in southwestern Virginia. The "Whitesburg" and the "Ottosee" as developed on Walker Mountain may not be so different in age as might be inferred from the stratigraphic interval of several hundred feet which separates them. If the intervening "Athens" accumulated relatively rapidly, the Walker Mountain "Ottosee" and "Whitesburg" may have been deposited very close to one another in time. According to the proposed interpretation, the "Athens" at Harrisonburg is not the same time-rock unit as the Walker Mountain "Athens." The Porterfield "Whitesburg and Walker Mountain "Ottosee" may be tongues extending from a solid mass of nodular, fossiliferous limestone (the Clinch Mountain Ottosee) and into a thicker body of black shale and black limestone (the Virginia Athens), which, in turn, changes toward the north into a thinner body of nodular, fossiliferous limestone (the Chambersburg beds below the *Reuschella edsoni* zone) The fact that a little Chambersburg overlies the highest "Athens" at Harrisonburg and Lacey Spring does not indicate that all the "Chambersburg" is necessarily younger than the "Athens." Such a relationship is denied by occurrences of the same fossils in the "Athens" and "Chambersburg" and by obvious dovetailing of the two characteristic lithologies. The seeming absence of *Nidulites* and *Cryptophragmus* in the vicinity of Staunton is believed to indicate that the highest Chambersburg beds there, like the lower and middle parts of the formation farther north, have passed laterally into black shales and black limestones of "Athens" type. Conceivably, these organisms were living elsewhere in the Appalachian sea when the uppermost beds of the "Athens" of the Staunton area were laid down. They may have been restrained from that and certain other sections of the sea bottom by unfavorable sedimentary conditions and, hence, may have not been generally available for burial in the accumulating "Athens" black sediments. Just as sporadic occurrences of Normanskill graptolites have already been discovered in the Chambersburg (Geologic section 17), so it is to be expected that occasional specimens of *Nidulites*, *Cryptophragmus*, and other "Chambersburg" fossils will be encountered in beds of "Athens" lithology in the course of future study of the belts southeast of Staunton. Along the western side of the Shenandoah Valley, cobbly beds of

"Chambersburg" type extend farther south than in the middle and eastern belts and persist at least as far as Collier Creek, a few miles southwest of Lexington, where they compose most of the interval between the Martinsburg and the *Dinorthis atavoides* zone. In the excellent section of the lower Middle Ordovician near Dunkard Church, west of Natural Bridge, the "Chambersburg" seems to have been almost entirely supplanted by the "Athens" (Geologic section 43).

The proposed interpretation would allow for more or less continuous sedimentation in the Appalachian trough throughout Middle Ordovician time, though not without shifts in environments of deposition. Previous interpretations of the lower Middle Ordovician, on the other hand, demand shifting seas and interrupted sedimentation.

PRE-CHAMBERSBURG LIMESTONES FROM PENNSYLVANIA TO VIRGINIA

In Pennsylvania, particularly in the section 2 miles southwest of Marion, the Chambersburg is underlain by about 1050 feet of limestone younger than the Beekmantown. Since the possible relations of this thick succession to the *Tetradium syringoporoides*, *Dinorthis atavoides*, and *Hesperorthis* zones of the Shenandoah Valley have not been considered previously, they are discussed here.

As previously indicated, the 150 feet of calcilutite with *Tetradium cellulosum*, which Stose and others identified as Lowville, is faunally and lithologically inseparable from the underlying 208 feet of beds formerly misidentified as Stones River limestone. This 358-foot succession comprises the upper of three distinct lithologic zones between the Chambersburg and Beekmantown in the Marion section. The middle division (Geologic section 4, units 2 to 12) is 600 feet thick and composed of dark-gray, granular, cherty limestone, much of which is relatively unfossiliferous. *Maclurites* is common in several beds in the lower 200 feet and particularly so not far above the base. Cherty limestones near the top of the *Maclurites*-bearing beds contain *Hesperorthis*, *Multicostella saffordi*, a small *Sowerbyella*, and *Camerella*. These fossils occur together in the same type of limestone in the *Hesperorthis* beds in the Staunton area. The lowest division of the "Stones River" in the Marion section, unconformably overlies the Beekmantown and consists of 30–60 feet of dove-gray calcilutite with numerous gastropods and *Tetradium syringoporoides*.

At Wilson, Maryland, the lower dove-gray calcilutite is somewhat more than 100 feet thick (Geologic section 5). It is directly succeeded by 420 feet mainly of light-gray calcilutite similar to the 358-foot zone with *Tetradium cellulosum*, near Marion, Pennsylvania. The only dark bed at all comparable to those comprising the 600-foot cherty zone of the Marion section is but 4 feet thick and is intercalated in beds containing *Tetradium cellulosum*. At Wilson, the entire 600 feet of cherty beds at Marion, Pennsylvania, is either absent or displaced by *Tetradium cellulosum* beds comprising an equivalent, dove limestone facies. About 5 miles farther south, in the same belt of outcrop, the same general succession, though somewhat thinned, is exposed in the abandoned quarries at Pinesburg Station, Maryland. The thick massive calcilutite at the base forms bluffs overlooking the Potomac River. The succeeding beds, extensively exposed, apparently contain no representative of the cherty beds below the type Chambersburg.

At Martinsburg, West Virginia, the Chambersburg is directly underlain by 200 feet or less of dove-gray, *Tetradium syringoporoides*-bearing calcilutite which is unmistakably linked with the *Tetradium syringoporoides* beds of the Shenandoah Valley. Here, as in the Maryland sections, the cherty limestone seems to be absent.

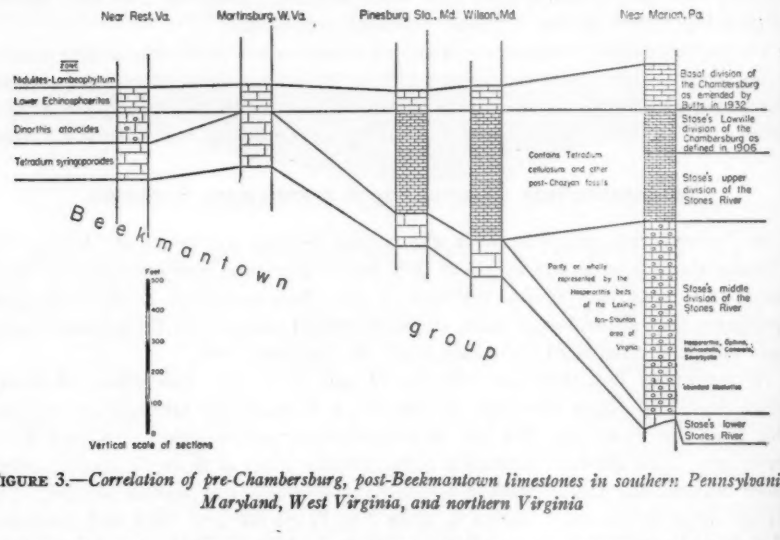
Near Rest, Va.
Martinsburg, W. Va.
Pinesburg Sta., Md.
Wilson, Md.
Near Marion, Pa.
Zone
Nidulites-Lambeophyllum
Lower Echinosphaerites
Dinorthis atavoides
Tetradium syringoporoides
Beekmantown group
Contains Tetradium cellulosum and other post-Chazyan fossils
Partly or wholly represented by the Hesperorthis beds of the Lexington-Staunton area of Virginia
Basal division of the Chambersburg as emended by Butts in 1932
Stose's Lowville division of the Chambersburg as defined in 1906
Stose's upper division of the Stones River
Stose's middle division of the Stones River
Stose's lower Stones River
Feet
Vertical scale of sections

FIGURE 3.—*Correlation of pre-Chambersburg, post-Beekmantown limestones in southern Pennsylvania, Maryland, West Virginia, and northern Virginia*

Since *Tetradium cellulosum* and the other Black River fossils listed by Stose (1909, p. 7) are unknown in the *Tetradium syringoporoides* beds of the Shenandoah Valley and at Martinsburg, West Virginia, the 358-foot zone of calcilutite with *T. cellulosum* below the type Chambersburg is not the same age as the beds identified as Mosheim by Butts in Virginia. The lithology and fossils of the lower calcilutite in the Marion section and at Pinesburg Station and Wilson, Maryland, is the same as the *Tetradium syringoporoides* beds of northern Virginia. The thick section of cherty limestone near Marion, Pennsylvania, which seems to be partly or wholly represented by the *Hesperorthis* beds of the Lexington-Staunton area of Virginia, is absent or displaced by dove limestone in the intervening sections at Martinsburg, Pinesburg Station, and Wilson. The thick body of dove-gray limestone above the cherty beds in Pennsylvania may wedge out somewhere between Pinesburg and Martinsburg. If the greater part or possibly all of the thick succession of cherty limestones in the "Stones River" near Marion, Pennsylvania, should prove to be equivalent to the *Hesperorthis* beds of the Lexington-Staunton area, as is suggested by strong similarity of fossils, the 358-foot zone of "Lowville" limestone near Marion would be in the stratigraphic position of the *Dinorthis atavoides* zone of the Shenandoah Valley. If this link can be positively established by further work, the Black River age of the *Dinorthis atavoides* beds would be established. The fossils in the 358-foot zone of dove limestone, including *Tetradium cellulosum*, are indicative of the Black River.

SUMMARY

The names Mosheim, Lenoir, Stones River, Whitesburg, and Athens are not applicable in northern Virginia. The so-called Mosheim of the Shenandoah Valley is no older than the type Lenoir and the so-called Lenoir is wholly unlike the type Lenoir. The true equivalents of the Stones River formations are not at the base of the lower Middle Ordovician as formerly supposed. The Virginia Whitesburg is inseparable faunally from the Virginia Athens, and the type Whitesburg is a facies of the true Athens. Neither name should be used in Virginia. In northern Virginia, Athens as a name for the familiar black shale-black limestone lithology is here supplanted by the revived name Liberty Hall.

Butts' emendation of the Chambersburg is a constructive modification because the *Tetradium cellulosum* beds originally classed with the Chambersburg are more closely linked with the underlying dove-gray, also *Tetradium cellulosum*-bearing calcilutites. The positive and unqualified identification of this limestone as Lowville is unjustified.

The age relations of the "Athens" in various parts of the Appalachian Valley of Virginia have been misinterpreted because it was assumed that the Athens was everywhere the same age. It cannot be demonstrated that the 1300 feet of "Athens" at Harrisonburg is the precise time equivalent of the 450 feet of so-called Athens along Walker Mountain in southwestern Virginia. The differences in fauna between the Chambersburg and the "Whitesburg-Athens" have been overstressed as evidence that the two formations are of different ages and with disregard for the obvious faunal similarities of the two formations. The facies concept has not received proper consideration in previous interpretations of the lower Middle Ordovician in northern Virginia. Certain fossils, particularly *Cryptophragmus antiquatus*, *Nidulites pyriformis*, and Normanskill graptolites have been assumed to have infallible correlative value, but without adequate basis. *Nidulites* is not confined to the Chambersburg, and *Cryptophragmus antiquatus* seems to range through the entire Black River group and possibly up into the lower Trenton.

PROPOSED CLASSIFICATION

GENERAL STATEMENT

A formation should be both a genetic and a mappable unit. The use of a formation name should be confined to the relatively limited province wherein essential contemporaneity of deposition seems reasonably certain. False paleogeography and false geochronology are read from misidentified beds. New stratigraphic names should be proposed only if they facilitate a clearer and more accurate understanding of geologic events. On this premise, the following revised classification of the lower Middle Ordovician of the Shenandoah Valley is proposed.

NEW MARKET LIMESTONE

Name.—The name New Market limestone is proposed for the succession of predominantly dense, fine-grained limestone above the Beekmantown and below the dark-gray limestones of the *Dinorthis atavoides* zone (Lincolnshire limestone).

The name is taken from a town on U. S. Route 11 in southern Shenandoah County, Virginia. A continuous section of the formation is exposed in the Madden quarry 0.65 mile west of the intersection of Road 735 and U. S. Route 11 in New Market.

Lithology.—Where typically developed, the New Market consists mainly of dove-gray, high-calcium limestone. As exhibited in the type section, two divisions are generally recognizable: a lower zone, composed mainly of thin-bedded dove-gray calcilutite in many places with a few feet of limestone-and dolomite-pebble conglomerate at the base; and an upper zone which is thick-bedded to massive and nearly free of insoluble matter.

Geologic section 9.—Type section of the New Market limestone, in the Madden quarry, near New Market, Virginia

	Thickness Feet	Thickness Inches
New Market limestone (83½ feet)		
28. Calcilutite, dove gray, pure	9	
27. Calcilutite, mottled dove gray and taupe gray	3	
26. Calcilutite, dove gray to dark gray	15	
25. Calcilutite, thick-bedded, mottled dove gray and brownish gray; has irregular, hackly fracture	11	
24. Calcilutite, light gray, with buff, clayey streaks	1	6
23. Calcilutite, dark gray, with irregular veins of white calcite	6	
22. Limestone, finely granular, dark bluish gray		3
21. Calcilutite, dove gray, massive; contains coarse stringers of white calcite	8	
20. Limestone, clastic-textured; contains irregular fragments of calcilutite		10
19. Calcilutite, dove gray	1	
18. Limestone, clastic-textured, contains large irregular fragments of calcilutite		9
17. Limestone, steel gray, fine-grained		6
16. Limestone, dove gray, irregular, clastic texture; seems to be result of reworking of partly consolidated lime muds	7	6
15. Limestone, drab gray, impure, fine-grained	1	6
14. Calcilutite, dove gray, with coarse calcite veins	2	6
13. Calcilutite, drab gray, shaly		5
12. Calcilutite, taupe gray; contains thin yellowish crinkled streaks	2	6
11. Limestone, fine-grained, drab gray, impure		3
10. Calcilutite, dove gray; abundant stringers of calcite	2	4
9. Calcilutite, impure, pale drab gray		4
8. Calcilutite, dove gray; abundant stringers of calcite	2	8
7. Calcilutite, yellowish gray, argillaceous		4
6. Calcilutite, dove gray, medium-bedded		6
5. Calcilutite, argillaceous, thin-bedded, yellowish gray		5
4. Calcilutite, dove gray	1	
3. Calcilutite, thin-bedded, with irregular calcite stringers	1	6
2. Calcilutite, drab gray, impure	1	10
1. Clastic limestone, drab gray	1	
Beekmantown group		

Local reworking of the lime muds soon after deposition is indicated by numerous clastic-textured limestones. The upper division is the quarry rock of northern Virginia. The massive, fluted ledges made by these beds are characteristic.

In the westernmost belts of the Shenandoah Valley, the basal layers of the New

Market are locally drab-colored impure dolomitic limestones, pebble conglomerates, and shaly beds which resemble closely the Blackford formation of southwestern Virginia (Cooper and Prouty, 1943, p. 862–863 ; Cooper, 1944, p. 36–39, 55–56). These beds are best developed along U. S. Route 250, about 3.5 miles west of Staunton and in another section 1.2 miles N. 75° W. of Broadway, Shenandoah County, along State Highway 256 (Geologic sections 31 and 23).

In a few sections, particularly along U. S. Route 33 about 5 miles southeast of Harrisonburg, thin cherty dark-gray granular limestones, like those in the overlying *Dinorthis* zone, are intercalated in the lower part of the New Market (Geologic section 28). In the east end of the quarry of the Staunton Lime Company (Geologic section 33), the lower few feet of the New Market limestone is a calcarenite, stringers and pockets of which fill fractures and cavities in the underlying Beekmantown dolomite.

On the west side of the Massanutten syncline, the New Market has its thickest and most characteristic development. The maximum thickness of 250 feet (Geologic section 11) was measured in a section 4 miles west of Edinburg, Shenandoah County. In most sections west of Massanutten Mountain, the thickness is 75–150 feet.

East of the Massanutten syncline, the New Market is much thinner and is locally absent. The two-fold division recognized on the west side of the syncline is less distinct, and the average thickness is considerably less than 50 feet. Locally, between Front Royal and U. S. Highway 33, the characteristic dove-gray beds are underlain by a cobble or boulder conglomerate, the larger fragments of which are several feet in diameter. The matrix is either dolomite or limestone, and the fragments are of similar composition. In one section, a quarter of a mile northwest of Leaksville, Page County, the boulder beds are over 100 feet thick and suggest a talus accumulation. The coarse conglomerates are tentatively classed with the New Market, but on further study they may warrant recognition as a separate formation.

Fossils.—Tetradium corals, mostly of the single-tubed variety and generally identified as *Tetradium syringoporoides* Ulrich (Pl. 2, fig. 5), is the only common fossil. Occasional ostracodes, generally identified as *Leperditia fabulites* (Conrad), occur in the shaly layers. The basal calcarenite of the New Market in the quarry of the Staunton Lime Company (Geologic section 33) contains a profusion of small tumid rhynchonellids indistinguishable from *Rostricellula pristina* (Raymond) (Pl. 2, fig. 16) which occurs in the lower part of the Blackford in Russell County, Virginia (Cooper, 1943, p. 1854) and in the type Lenoir of Tennessee.

Age and correlation.—The New Market limestone is essentially the same as the unit identified by Butts as Mosheim in most parts of northern Virginia. It corresponds to the high-calcium limestones quarried at Martinsburg, West Virginia, and to the lower 125 feet of dove-gray calcilutite at Wilson and Pinesburg Station, Maryland. It also seems to be represented by the 30- to 60-foot succession of dove-gray calcilutites and associated magnesian beds immediately above the Beekmantown, 2 miles southwest of Marion, Pennsylvania.

The New Market limestone is not the same as the Five Oaks limestone of south-

western Virginia, which has also been identified by Butts as Mosheim. The Five Oaks directly overlies a cherty limestone containing *Dinorthis holdeni* and camerellids like those in the *Hesperorthis* beds of the Lexington-Staunton area, whereas the New Market underlies the beds with *Hesperorthis* and *Dinorthis holdeni*. Possibly the thin *Tetradium*-bearing calcilutite between the *Hesperorthis* and *Dinorthis atavoides* zones along Little North Mountain near the Augusta-Rockbridge county line, west of Greenville, represents the Five Oaks. The New Market occupies the stratigraphic position of the dolomitic, shaly beds of the Blackford formation of southwestern Virginia (Cooper, 1944, p. 39–40, 57–58). The occurrence of *Rostricellula pristina* in the basal layers of the New Market at Staunton and in the Blackford formation near Hansonville, Russell County (Cooper, 1945, p. 271), links these two formations with the type Lenoir of Tennessee. Part, possibly all, of the New Market is Chazy.

WHISTLE CREEK LIMESTONE

Name.—The name Whistle Creek limestone is here introduced for the cherty limestones containing the *Hesperorthis* fauna, which succeed the New Market limestone and underlie either the coarse-grained "Holston" limestone of the Lexington area or the *Dinorthis atavoides* zone. The type section (Geologic section 40) is between U. S. Route 60 and Whistle Creek about 2 miles N. 40° W. of Lexington, Rockbridge County, Virginia.

Lithology.—The Whistle Creek limestone is prevailingly dark-bluish to brownish-gray, irregularly bedded, very cherty limestone. In many places, the position of the Whistle Creek limestone is indicated by blocks of fossiliferous, punky chert. Where the Whistle Creek is in direct contact with the *Dinorthis atavoides* zone, the two can be distinguished only by fossils. Geologic sections 31–43 show the general character and range in thickness of the Whistle Creek limestone in the Shenandoah Valley and James River districts. The formation is believed to be absent north of Staunton.

Fossils.—The known fauna of the Whistle Creek consists of several new species belonging to the genera *Hesperorthis*, *Valcourea*, *Mimella*, and *Camerella*, as well as *Dinorthis holdeni* (Willard) and *Multicostella* cf. *M. saffordi* (Hall and Clarke). Except for *Dinorthis* these genera are common in the New York Chazy and also occur in the typical Lenoir of Tennessee, but the Whistle Creek forms cannot be identified with the species occurring in those formations. Many of the characteristic fossils of the Whistle Creek limestone have been figured by Butts (1941, Pls. 73–74).

Age and correlation.—The precise age of the Whistle Creek beds has not yet been established. The middle part of the typical Lenoir of Tennessee, which is very probably older than the Whistle Creek limestone, contains fossils characteristic of the middle and Valcour divisions of the New York Chazy; hence, the Whistle Creek, if at all Chazy, could be represented only in the upper part of the Valcour. Probably the Whistle Creek limestone, as well as some of the succeeding beds, is younger than the Chazy and older than typical Black River. The blocky chert

of the Clinch Valley district in southwestern Virginia correlates with the Whistle Creek limestone.

LINCOLNSHIRE LIMESTONE

Name.—The Lincolnshire limestone was named by Cooper and Prouty (1943, p. 863) from a creek, about 2 miles northeast of North Tazewell, Tazewell County, Virginia. Its extension into the northern portion of the Appalachian Valley seems justified on the basis of field work completed since the name was introduced. The Lincolnshire has been traced southwest from Tazewell to Luttrell, Tennessee, and has been identified in numerous other places still farther southwest in Tennessee. Northeast of Tazewell County, the Lincolnshire is easily recognizable in Giles County, particularly along New River at Ripplemead and along the Norfolk and Western Railway 0.3 mile south of Berton Station. Willard's holotype of *Sowerbyites* [*Plectambonites*] *triseptatus* came from the latter section. Somewhat farther northeast, on the Salem block of the Pulaski overthrust, the Lincolnshire, with many of its characteristic fossils, is prominently displayed in and just south of the quarry of the Montgomery Lime Co., near Ellet, Montgomery County. This belt continues northeastward to the vicinity of Roanoke. It is the dark-gray cherty limestone with dinorthids, separating the "Mosheim" and "Holston" in the quarries at Eagle Rock, Botetourt County, Virginia. In this county, it also forms part of the limestone belt not far south of U. S. Route 11 and extending several miles northeast to the Rockbridge-Botetourt county line. The Lincolnshire of this belt is well exposed along a secondary road about midway between Rocky Point and U. S. Route 11. There, as well as in many sections farther northeast, in Rockbridge and Augusta counties, coarse-grained light-gray calcarenites are intercalated in or closely associated with the cherty limestones containing *Dinorthis atavoides* and its associates. Except for these clastic beds, which represent local variations in the deposition of a widespread formation, the *Dinorthis atavoides* zone of northern Virginia closely resembles the Lincolnshire of southwestern Virginia, contains the same fossils, and occupies the same stratigraphic position.

The name Strasburg limestone was introduced without definition by Ulrich (1939, p. 106) for a part of the succession herein identified as Lincolnshire. Later Ulrich and Cooper (1942, p. 622) used it as equivalent to the "upper Lenoir" of Tennessee. Since the name had received no precise definition or description at the time Lincolnshire was introduced (1943), Strasburg is considered invalid.

As herein used the Lincolnshire is a time-stratigraphic name for the beds above the New Market or Whistle Creek limestone, and below either the brownish-weathering "trilobite beds" identified by Butts as Whitesburg, or below the base of the lower *Echinosphaerites* zone as developed where the "Whitesburg" is not separately recognizable.

Lithology.—The Lincolnshire along Tumbling Run (Geologic section 10) is characteristic of the formation in the northern part of the Shenandoah Valley, where intercalated calcarenites are relatively thin and inconspicuous.

Geologic section 10.—Lincolnshire limestone along Tumbling Run, 2 miles southwest of Strasburg, Virginia

	Thickness Feet
Lincolnshire limestone (132 feet)	
6. Limestone, fine-grained, cobbly, sparsely cherty	27
5. Limestone, dense, black, cherty; contains *Mimella* sp., *Sowerbyites triseptatus*, *Multicostella saffordi* and *Dinorthis atavoides*	35
4. Limestone, dark gray, granular, cherty; contains intercalated beds and lenses of coarse-grained limestone crowded with *Girvanella*	32
3. Limestone, fine- to medium-grained, cherty, black	29
2. Limestone, thin-bedded, platy, dark gray, no chert	4.5
1. Limestone, coarse-grained, medium gray, no chert	4.5
New Market limestone	

North of the latitude of Harrisonburg, the Lincolnshire averages 50 to 100 feet thick, but on the east side of the Massanutten syncline the thickness is generally less than 60 feet. The maximum thickness, about 200 feet, occurs locally south of Staunton (Geologic section 36).

In the vicinity of Staunton and southward for several miles to Mint Spring, coarse-grained calcarenites of "Holston" type are seen variously below and within the main body of drab-gray cherty limestone containing *Dinorthis atavoides*. Locally, about 6.4 miles south of Staunton (Geologic section 35), a 153-foot zone of coarse-grained "Holston" type limestone underlies a very thin development of the cherty *Dinorthis atavoides* beds. In another section, near the junction of Roads 652 and 608, 6.7 miles S. 21° E. of Staunton, light-gray to white coarse-grained calcarenite occurs just below cherty limestone containing abundant *Sowerbyites triseptatus* (Geologic section 34). Another calcarenite, slightly darker, occurs somewhat higher (Geologic section 34, unit 5). The fact that the typical cherty Lincolnshire is abnormally thin wherever the subjacent "Holston" calcarenite is well developed and that tongues of calcarenite are intercalated locally within the cherty *Dinorthis atavoides* beds indicates that the calcarenite is a facies of clastic limestone equivalent to the typical cherty Lincolnshire.

Near Murat, a few miles southwest of Lexington, the light-gray "Holston" type calcarenite almost completely supplants the cherty *Dinorthis atavoides* beds (Geologic section 41). Two miles northwest of Lexington, the so-called Holston contains intercalated beds of dark impure limestone and is capped locally by cherty beds with *Dinorthis atavoides* and *Sowerbyites triseptatus* (Geologic section 40). Along Collier Creek, southwest of Lexington, five thin tongues of light-gray to white calcarenite are intercalated within the *Dinorthis-Sowerbyites* zone (Geologic section 42). Thus, even in the Lexington area, there is ample justification for considering the so-called Holston to be a clastic limestone facies of the typically cherty Lincolnshire.

As previously indicated (Cooper, 1944, p. 59–60), Holston should not be used as a time-stratigraphic name. In Tennessee, as well as in Virginia, there are Holston type beds at many different horizons in the Middle Ordovician (Keith, 1901, p. 3). Therefore, Murat could be revived on the grounds that the original definition was misunderstood and also by reason of the fact that Holston is not strictly applicable. It is proposed herewith to revive Murat and to use it for the name of a characteristic

facies of clastic, reefy limestone, which is an essential part of the Lincolnshire limestone.

Fossils.—The fossils in the Lincolnshire include:

Algae
- *Girvanella* sp.
- *Solenopora* sp.

Sponges
- *Nidulites ovoides* Butts (1941, Pl. 76)

Bryozoans
- *Dekayella* sp.
- *Mesotrypa* sp.
- *Nicholsonella* sp.
- *Rhinidictya* sp.

Brachiopods
- *Camerella* sp.
- *Clitambonites* sp.
- *Dactylogonia* sp.
- *Dinorthis atavoides* Willard (Pl. 2, fig. 9)
- *Multicostella* cf. *M. saffordi* (Hall and Clarke)
- *Opikina* sp.
- *Sowerbyella* sp.
- *Sowerbyites triseptatus* (Willard) (Pl. 3, figs. 21–23)

Gastropods
- *Maclurites cf. M. "magnus"* Lesueur
- *Subulites* sp.

Trilobites
- *Amphilichas* sp.
- *Homotelus* sp.
- *Illaenus* sp.
- *Sphaerexochus* sp.

Butts (1940, p. 153) reports *Glaphurina brevicula*, the holotype of which Ulrich (1930, p. 46) collected and described from the "Holston" about 2 miles "west" of Lexington This is an unusual occurrence, since most of the Appalachian Telephidae occur in the "Whitesburg" or lower part of the "Athens."

Age and correlation.—The Lincolnshire is essentially the same as Butts' Lenoir of many localities in northern Virginia, but it includes the lower beds of the Chambersburg identified by Butts (1940, p. 197–198) along Tumbling Run, near Strasburg, Shenandoah County. It also includes his Holston of the Lexington area. Some of the Effna limestone (Cooper, 1944, p. 59–64) may be essentially the same as some of the Murat calcarenites of the Lexington area, but the bulk of the Effna in the Porterfield quarry, near Saltville, Smyth County, Virginia, seems to be a reef in the "Whitesburg." The Lincolnshire is believed to be younger than typical Chazy, by reason of the strong dissimilarity of fossils and by the fact that it occurs considerably above true Lenoir equivalents in the Blackford formation of southwestern Virginia. Dominant Lincolnshire elements, particularly the genera *Dinorthis*, *Sowerbyella*, and *Sowerbyites*, are wholly unknown in any of the Chazy formations of New York.

There is some suggestion that the Lincolnshire limestone is partly or wholly equivalent to the 358-foot succession of dove limestone containing *Tetradium cellulosum*, near Marion, Pennsylvania. Fossils collected from the cherty limestones below the *Tetradium cellulosum* beds are succeeded by the same beds as overlie the Lincolnshire in the Shenandoah Valley. Thus the Lincolnshire and the *Tetradium cellulosum* beds appear to have the same stratigraphic position. The possible

equivalency of these two units should be fully explored. If a definite correlation can be established, the post-Chazy age of the Lincolnshire, as herein suggested, will be positively affirmed.

EDINBURG FORMATION

Definition.—The name Edinburg formation is proposed for the stratigraphic interval above the Lincolnshire limestone and below the *Reuschella "edsoni"* zone in the Shenandoah Valley. Although the Edinburg is largely limestone in most parts of northern Virginia, its lithology varies greatly from place to place. The type section is 1.5 miles N. 61° E. of Edinburg, Shenandoah County.

Lithology.—The lithologic variations of the Edinburg noted in the Shenandoah Valley can be resolved into two principal facies and their mutual gradations. One facies is composed mainly of black limestone and black shale, for which the name *Liberty Hall facies of the Edinburg formation* is proposed. So used, Liberty Hall refers to the same succession of black strata originally included in the "Liberty Hall limestone" by Campbell (1905). Designation as a facies name signifies that the beds exhibiting this lithology do not everywhere fall within the same precise stratigraphic limits. The name *Lantz Mills facies of the Edinburg formation* is proposed for the contrastingly cobbly to nodular, buff-weathering limestone which is most typically developed near Lantz Mills, about 4.6 miles N. 69° W. of Edinburg.

On the east side of the Massanutten syncline, alternation of the Lantz Mills and Liberty Hall facies is well shown in a section about 1.7 miles S. 10° W. of Wadesville, Clarke County (Geologic section 17), but southwest of Riverton, Warren County, the Edinburg is all of the Liberty Hall facies (Geologic sections 25 and 29) with black shale somewhat more abundant than black limestone. In the belt along U. S. Route 11 from Strasburg to Mt. Jackson, the Lantz Mills facies forms an especially prominent tongue in the lower 100 feet of the Edinburg, and in the same belt cobbly layers at or near the top persist farther southward beyond the Harrisonburg area (Geologic sections 24 and 28). In the belts farther west, the Lantz Mills facies composes practically all the lower *Echinosphaerites* and *Nidulites-Lambeophyllum* zones as far southwest as Hamburg, Shenandoah County. South of this village, as is well shown along State Highway 260 just east of Forestville and along State Highway 263 northwest of Mt. Jackson, the Edinburg is mainly slabby, dense black limestone somewhat intermediate in character between the cobbly limestone and Liberty Hall facies. Tongues of the Lantz Mills facies persist beyond the Shenandoah Valley into the area west of Lexington and possibly as far as James River. Cobbly limestones are especially prominent along Collier Creek, about 6.5 miles S. 80° W. of Lexington (Butts, 1940, Pl. 32A) and in the excellent section 0.25 mile south of Dunkard Church and 6.9 miles S. 80° W. of Natural Bridge, where cobbly beds occur above and below black shales with Normanskill graptolites.

The few feet of brown-weathering granular limestones with abundant trilobites at the base of the "Athens," comprise an excellent key zone in the southern part of the Shenandoah Valley. The lithology of these beds is the most distinctive feature; their fossils occur also in a substantial part of the succeeding "Athens." The brown-weathering "trilobite beds" and, locally, overlying beds of "Athens" type containing some of the same fossils were identified previously as Whitesburg. As previously

FIGURE 4.—*Facies changes in the Edinburg formation between Harrisonburg and the Virginia-West Virginia line*

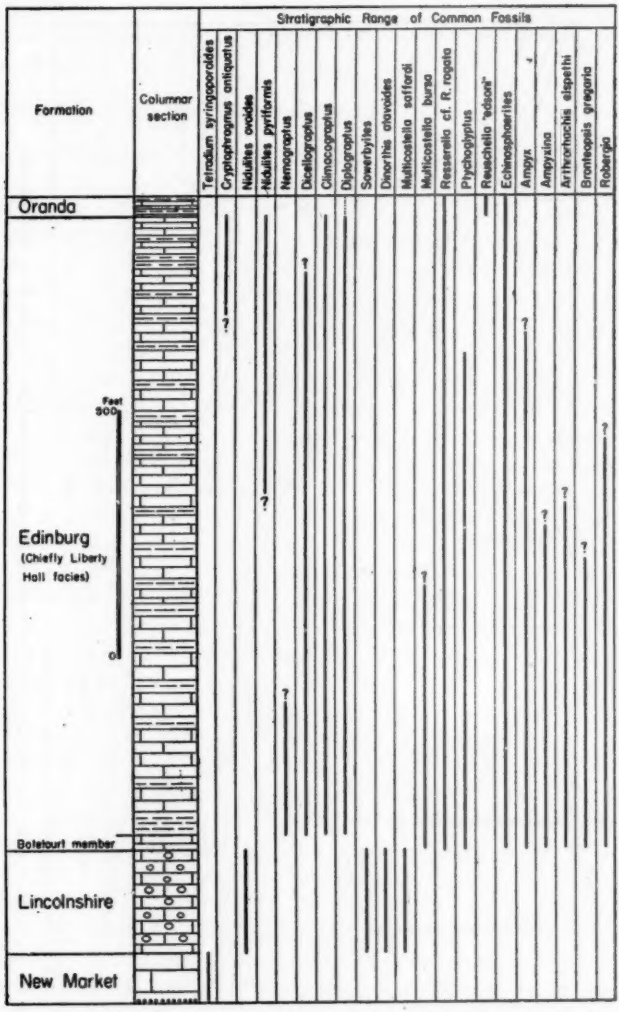

FIGURE 5.—*Columnar section of the lower Middle Ordovician formations near Harrisonburg, Virginia*

shown, use of the name Whitesburg in Virginia should be held in abeyance until the relative position and age of the various related Tennessee formations are clarified. The name *Botetourt* (pronounced Bottitot) *limestone member of the Edinburg formation* is proposed for the brown-weathering granular limestone above the Lincolnshire and below beds of Liberty Hall type, which occur at the base of the Edinburg. The type section is in Botetourt County, on the deeply gullied hillsides about 0.25 mile south of Dunkard Church and 6.9 miles S. 80° W. of Natural Bridge (Geologic section 40).

West of U. S. Route 11, between Forestville and Saumsville in Shenandoah County, a rather pure, dove-gray limestone occurs above the *Nidulites-Lambeophyllum* zone and below the *Reuschella "edsoni"* beds. For these beds, which form the topmost division of the Edinburg in this section of the Shenandoah Valley, the name ***St. Luke limestone member*** is proposed. At the type locality, a mile S. 60° E. of St. Luke, the member is 90 feet thick, but in the section west of Lantz Mills (Geologic section 12) it is calcarenite, except for the uppermost 20 feet or so which is as fine-grained as the beds at St. Luke. A few miles southwest of Forestville, the St. Luke calcarenites are largely supplanted by black limestone. The thin intercalations of calcarenite with *Cryptophragmus*, found in beds of the Liberty Hall facies near the top of the Edinburg, 0.4 mile west of Linville Station and in the Edinburg belt between Woodstock and New Market (Geologic section 21–22), are taken to indicate that the St. Luke limestone is represented in the upper part of the Edinburg beyond the Forestville-Saumsville sector in which the member is mappable.

The above-named facies and members of the Edinburg are best developed in the following sections:

Geologic section 11.—Type section of the Edinburg formation about 1.5 miles N. 61°E. of Edinburg, Virginia

	Thickness Feet
Reuschella "edsoni" zone (24 feet)	
Edinburg formation (455 feet)	
14. Limestone, black, slabby, fine-grained (Liberty Hall facies)	12.5
13. Limestone, medium- to coarse-grained; contains many *Camarocladia* and *Cryptophragmus antiquatus*	30
12. Limestone, fine-grained, gray, apparently without *Cryptophragmus* (Liberty Hall facies)	22
11. Limestone, dense, black, slabby; contains tubes without septa which belong to weathered, calcite-filled *Cryptophragmus* (Liberty Hall facies)	26
10. Limestone, dense, black, slabby; contains shaly partings; *Nidulites* rather common (Liberty Hall facies)	69
9. Limestone, buff weathering, cobbly, contains rather abundant *Nidulites* and *Lambeophyllum* (Lantz Mills facies)	60
8. Limestone, black, slabby; contains sparse *Nidulites* (Liberty Hall facies)	50
7. Limestone, cobbly, buff weathering; contains *Nidulites* (Lantz Mills facies)	61
6. Limestone, black, slabby (Liberty Hall facies)	68
5. Limestone, buff weathering, cobbly, contains *Echinosphaerites aurantium*, *Homotelus simplex*, *Calliops*, sp., *Ampyx hastatus*, *Corineorthis*, *Resserella* cf. *R. rogata*, *Christiania* cf. *C. trentonensis*, *Dinorthis* cf. *D. transversa*, *Öpikina minnesotensis*, *Sowerbyella*, *Conotreta* sp., and *Conularia* sp. (Lantz Mills facies)	57
4. Calcarenite, dark gray, suggestive of the Botetourt limestone member but more like the basal granular beds at Strasburg junction (Geologic section 19, unit 17)	9
Lincolnshire limestone (167 feet)	
3. Limestone, granular, dark bluish gray, very cherty; contains *Sowerbyites* and *Maclurites* and intercalations of calcarenite with abundant *Girvanella*	151
2. Limestone, medium gray, granular, no chert	16
New Market limestone (84 feet)	
1. Calcilutite, dove gray; well exposed in bluff along Shenandoah River	84
Beekmantown dolomite	

Geologic section 12.—Middle Ordovician limestones along Swover Creek, 4.6 miles N. 69° W. of Edinburg, Virginia

	Thickness Feet
Reuschella "edsoni" zone	
Edinburg formation (413 feet)	
St. Luke limestone member	
12. Calcilutite, light gray, medium-bedded; same beds exposed 1 mile to the east, near intersection of Roads 691 and 692, where they contain *Cryptophragmus antiquatus*	20
11. Calcarenite, light gray, medium-bedded, partly covered	30
10. Calcarenite, coarse-grained, medium-bedded; faintly cross-laminated; contains *Foerstephyllum "halli"* (Nicholson)	41
9. Calcarenite, medium gray, thick-bedded; contains *Doleroides*, *Zygospira*, *Oligorhynchia*, and *Rhinidictya*	5
Lantz Mills facies	
8. Limestone, nodular, argillaceous; contains thin intercalations of limestone pebble conglomerate; *Nidulites pyriformis* Bassler occurs in the lower beds	50
7. Limestone, cobbly, argillaceous, weathers buff gray; *Nidulites* very abundant; top beds contain *Nidulites*, *Lambeophyllum*, and *Cryptophragmus antiquatus* (Pl. 2, fig. 1), and a large strophomenoid	53
6. Limestone, nodular to cobbly, argillaceous, weathers buff; contains large *Christiania* and *Nidulites*	17
5. Limestone, nodular to argillaceous; weathers buff; few ledge-making beds near the middle and the base; contains *Homotelus simplex*, *Echinosphaerites aurantium*, *Dinorthis* cf. *D. transversa*, *Öpikina* cf. *Ö. minnesotensis*, and *Resserella* cf. *R. rogata*	188
Lincolnshire limestone (111 feet)	
4. Limestone, dark gray, finely granular, sparsely cherty	38
3. Limestone, dark bluish gray, cherty, scantily fossiliferous; contains *Sowerbyella*, *Multicostella*, *Mimella*, *Girvanella*, and *Nidulites ovoides*	73
New Market limestone (250 feet)	
2. Calcilutite, dove gray; massive, fluted outcrops	140
1. Calcilutite, dove gray, thinner-bedded than zone 2	110
Beekmantown dolomite	

Geologic section 13.—Middle Ordovician limestones adjacent to U. S. Route 11, 2 miles south of Harrisonburg, Virginia

	Thickness Feet
Reuschella "edsoni" zone	
Edinburg limestone (1,348 feet)	
Lantz Mills facies	
10. Limestone, cobbly, shaly; contains *Christiania* and *Resserella*; thin partings of granular limestone	25
9. Limestone, black, cobbly to slabby, contains *Nidulites pyriformis*	40
Liberty Hall limestone facies	
8. Limestone, dense, black, medium- to thin-bedded; many en echelon gash veins of white calcite	950
7. Limestone, dense, black, medium- to thick-bedded, with intercalated black graptolitiferous shales, not fully exposed	285
6. Shale, pinkish and flaky where weathered, black where fresh; contains graptolites	38
Botetourt limestone member	
5. Limestone, black, granular, contains *Bumastus*, *Bronteopsis*, and *Arthrorhachis*	10

	Thickness Feet
Lincolnshire limestone (51 feet)	
4. Limestone, black, fine-grained, irregularly bedded, with reddish streaks along the bedding	12
3. Limestone, black, cherty, granular	39
New Market limestone (161 feet)	
2. Calcilutite, dove gray, medium-bedded, pure	83
1. Limestone, compact, light gray	78
Beekmantown dolomite	

Fossils.—The faunal contents of the Edinburg vary considerably from place to place. The basal granular beds near Strasburg (Geologic section 19) and the Botetourt limestone member in the general vicinity of Harrisonburg (Geologic sections 24–25) contain many of the same fossils. These include: a large species of *Multicostella* very close to *M. bursa* (Raymond), *Ptychoglyptus virginiensis*, *Christiania* sp., *Orthambonites* sp., *Cyrtonotella* cf. *C. virginiensis* (Pl. 3, fig. 20) Butts, *Corineorthis* sp., *Resserella* cf. *R. rogata*, *Robergia*, *Bronteopsis gregaria*, *Arthrorhachis elspethi*, and *Ceraurus pleurexanthemus* (Pl. 3, fig. 8). In the eastern and southern sections of the Shenandoah Valley, the succeeding beds—all of Liberty Hall facies—contain the *Nemagraptus gracilis* fauna of the lower Normanskill and abundant trilobites mostly referable to the genera *Ampyx*, *Ampyxina*, *Robergia*, *Dionide*, *Robergia*, and *Remopleurides*. *Arthrorhachis elspethi* (Pl. 3, fig. 3–4), *Calliops annulatus*, *Bronteopsis gregaria*, and *Tretaspis reticulata* are somewhat less common. The *Nemagraptus* zone of graptolites and the associated trilobites are especially well displayed in fields east of U. S. Route 11 opposite Lacey Spring Post Office and just west of the same highway a mile or so north of the Caverns of Melrose south of New Market. These trilobites and several brachipods, also known to occur with the *Nemagraptus* fauna between Lacey Spring and Staunton, have been found in the lower *Echinosphaerites* and *Nidulites-Lambeophyllum* zones of Butts' Chambersburg in the Strasburg-Winchester-Wadesville district. Those brachiopods occurring in both the "Athens" and Chambersburg include *Lingula* cf. *L. nympha* Billings, *Resserella* cf. *R. rogata*, *Oxoplecia* aff. *O. simulatrix*, *Ptychoglyptus*, *Multicostella* cf. *M. bursa*, "*Leptobolus ovalis*," *Sowerbyella*, *Leptellina*, *Cyclospira*, and *Conotreta*. A few silicified specimens of *Diplograptus* have been etched out of limestone blocks from the lower beds of Butts' Chambersburg near Strasburg. Since the brachiopods and trilobites associated with these graptolites occur with the Normanskill fauna south of Mt. Jackson, it seems reasonable to infer that the silicified diplograptids near Strasburg are representatives of the *Nemagraptus* fauna. The upper part of the Edinburg, particularly in the areas of Butts' "Athens," contains numerous graptolites mostly referable to *Climacograptus* and *Diplograptus*, apparently without *Nemagraptus*. These genera have also been found in *Nidulites*-bearing beds identified by Butts as "Chambersburg" near Wadesville (Geologic section 17) and just below the *Reuschella* "*edsoni*" zone east of Lacey Spring. Thus the upper "Athens" of some areas and the upper "Chambersburg" are believed to correspond to the post-*Nemagraptus*, or upper, graptolite zone of the Normanskill. In the western part of

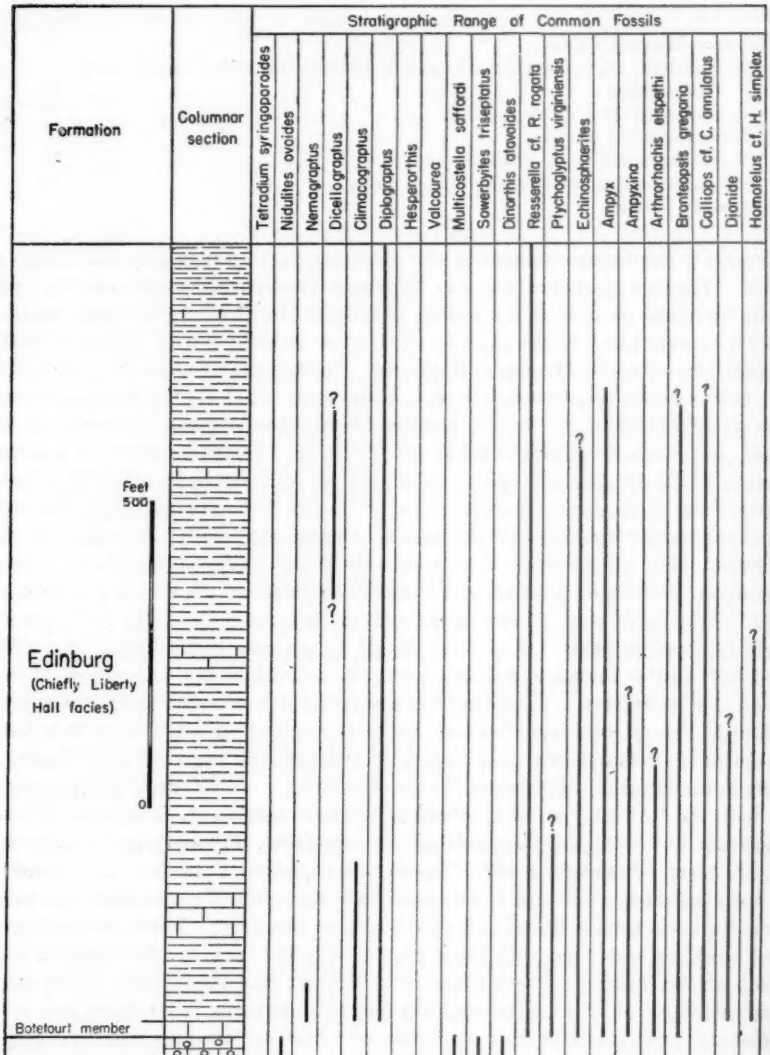

FIGURE 6.—*Columnar section of the lower Middle Ordovician formations southeast of Staunton, Virginia*

the Shenandoah Valley, where calcarenites occur in the upper part of the Edinburg, *Cryptophragmus antiquatus*, *Foerstephyllum "halli,"* *Camarocladia* cf. C. *rugosum*, and *Doleroides* occur. Occurrences of *Cryptophragmus antiquatus* in the sections

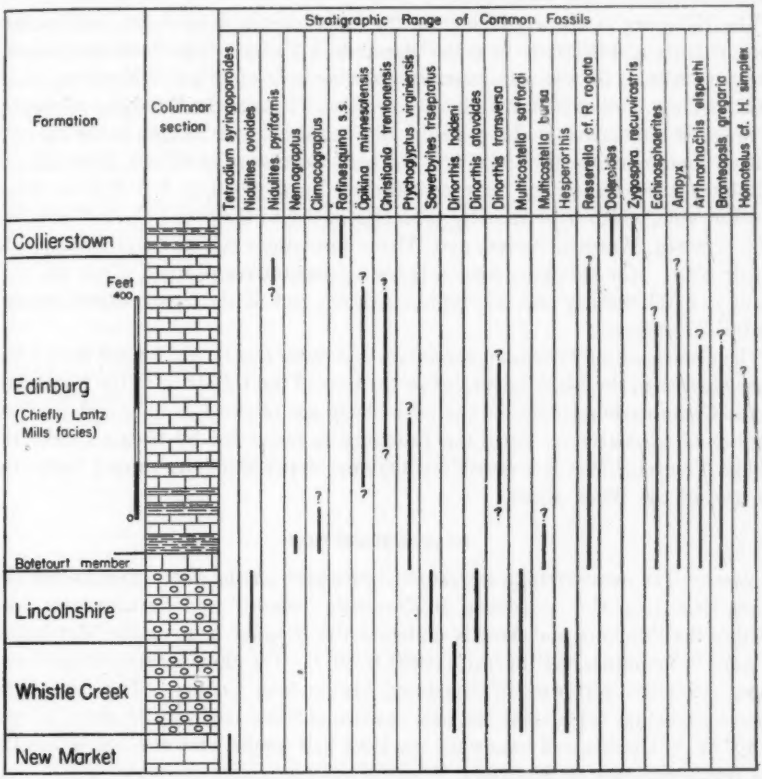

FIGURE 7.—*Columnar section of the lower Middle Ordovician formations southwest of Staunton, Virginia*

near Wadesville, Woodstock, and Lantz Mills indicate that this supposed guide fossil of the Lowville (Butts, 1928, p. 365) and Pamelia (Kay, 1944, p. 22–23) has a relatively long range.

Of particular interest are occurrences of numerous silty beds of Martinsburg lithology in the Edinburg, both in the Liberty Hall facies (Geologic section 28) and in the Lantz Mills facies (Geologic section 17). These silty beds contain *Resserella* cf. *R. rogata*, *Christiania* cf. *C. trentonensis*, *Bimuria lamellosa*, and *"Sowerbyella" pisum*. These layers may possibly indicate that beds of Edinburg age in some unstudied areas may have a Martinsburg facies as well as those facies identified in the present study.

Age and correlation.—The Edinburg corresponds to a substantial part of the Chambersburg formation of Pennsylvania. It is also equivalent to the Normanskill

shale of New York and contains representatives of limestones of Black River and possibly early Trenton age in New York and Ontario (Kay, 1937, p. 256–258; Okulitch, 1939, p. 337). Precise correlation with New York formations other than the Normanskill must await further study.

The Edinburg is also equivalent to the beds identified by Butts as Chambersburg, Athens, and Whitesburg in the Shenandoah Valley. The Botetourt limestone member includes the characteristically granular beds of Butts' Whitesburg in Virginia. Along Walker Mountain in southwestern Virginia, the Edinburg corresponds to the succession above the Lincolnshire and upward at least as high as the top of the Witten limestone (Butts' Lowville). In belts northwest of Clinch Mountain, the Edinburg is represented by beds identified by Butts (1940, p. 170–191) as Ottosee and Lowville, which have recently been classified into the Ward Cove, Peery, Benbolt, Gratton, Wardell, Bowen, and Witten formations (Cooper and Prouty, 1943, p. 863–880). The Edinburg also includes representatives of most, if not all, of the Tennessee Whitesburg and the typical Athens, and of the Stones River group of central Tennessee.

The occurrence of *Tetradium cellulosum* and other fossils, not known from formations older than the Black River, below the base of the Edinburg at the type section of the Chambersburg indicates the post-Chazy age of the Edinburg and its above-mentioned correlatives. Since the Edinburg is succeeded by beds no older than middle Trenton, there is a possibility that the upper Edinburg ranges higher than the top of the Black River.

ORANDA FORMATION

Name.—The name Oranda formation is proposed for the distinctive 30-foot zone, characterized by the occurrence of *Reuschella "edsoni"* and its associates, which overlies the Edinburg and directly underlies the *Sinuites* beds of the Martinsburg. It is the "*Christiania* bed" of Butts (1940, p. 201). The name is taken from a hamlet about 3.5 miles northeast of Strasburg, Shenandoah County. The type section (Geologic section 14) is along the new location of State Highway 55 about 2.7 miles S. 40° W. of Oranda and somewhat less than half a mile west of U. S. Route 11 in the north environs of Strasburg.

Lithology.—Despite its relative thinness, the Oranda is probably the most distinctive formation in the Middle Ordovician of the Shenandoah Valley. It is also of considerable importance as a reliable zone of reference, below which the facies changes in the Edinburg formation are observable between Lacey Spring and Winchester. About 0.4 mile west of Linville Station, Rockingham County, the Oranda overlies beds of the Liberty Hall facies; west of Lantz Mills (Geologic section 12) it succeeds the distinctive St. Luke limestone member; and along Tumbling Run and U. S. Route 11, southwest of Strasburg, it overlies cobbly unfossiliferous beds referable to the post-*Nidulites* zone (Geologic section 20). The Oranda is mainly developed in the Middle Ordovician belts west of U. S. Route 11. It is probably continuous in the westernmost belts of the Shenandoah Valley as far south as U. S. Route 250. East of the Massanutten syncline, the Oranda probably does not persist very far south of State Highway 274, Clarke County, although it is possibly

represented by the sandstone with granulated fossils, just above the Edinburg near Riverton, Warren County (Geologic section 18). The absence of the Oranda farther south in this belt makes it almost impossible to separate the "Athens" beds of the upper Edinburg from the overlying Martinsburg. The Oranda is apparently absent southeast of Harrisonburg.

The Oranda is composed mainly of very argillaceous limestone but contains metabentonitic clays, shales, and ledge-making siltstones. It forms the transition zone between the subjacent limestone and the succeeding sandy shales of the Martinsburg. Except in road cuts, the Oranda is almost nowhere fully exposed. Many of its metabentonites are unknown outside the type section.

Geologic section 14.—Type section of the Oranda formation along State Highway 55, 2.7 miles S. 40° W. of Oranda, Virginia

	Thickness Feet	Thickness In.
Martinsburg formation (lower beds exposed in road cut; 183 feet)		
48. Shale, sandy, black	60	
47. Metabentonite, buff		2–3
46. Shale, black	7	3
45. Metabentonite, apricot buff		4–5
44. Shale, black	8	2
43. Metabentonite, apricot buff		4
42. Shale, black	17	3
41. Limestone, secondary deposit composed of roundish masses of resinous calcite		2
40. Shale, black		6
39. Metabentonite, buff		2
38. Shale, black	37	5
37. Metabentonite, contains flaky laminae of secondary calcite and partings of black shale		6
36. Shale, black	11	6
35. Shale, silicified, cuneiform-jointed		6–10
34. Metabentonite, orange buff		5
33. Limestone, drab gray		2–3
32. Shale, black	30	
31. Sandstone, dark brownish gray		3
30. Shale, black, mealy, weathers in pencil-shaped slivers	2	3
29. Shale, drab gray, silty, cuneiform-jointed	1	7
28. Metabentonite, apricot buff		2–3
27. Siltstone, dark brownish gray, cuneiform-jointed, silicified		8–10
26. Metabentonite, buff		2
25. Limestone, cuneiform-jointed, silicified		3
24. Limestone, very impure, contains *Cryptolithus tesselatus*, *Isotelus* cf. *I. gigas*, and rather abundant *Sinuites*	5	4
Oranda formation (56 feet)		
23. Siltstone, black to dark gray, friable	2	6
22. Siltstone, cuneiform-jointed, silicified	2	
21. Siltstone, buff weathering, arkosic, bentonitic	1	
20. Siltstone, sandy, dark brown, cuneiform-jointed		9
19. Metabentonite, buff		1–3
18. Mudstone, dark gray, calcareous, silty; weathers smoke gray to drab gray; contains *Oxoplecia simulatrix* and *Resserella* cf. *R. rogata*	21	
17. Metabentonite and bentonitic shale		3

	Thickness Feet	In.
16. Mudstone, calcareous, lumpy, dark gray, silicified; basal surface crowded with *Echinosphaerites*; other beds contain *Reuschella, Eoplectodonta, Bimuria lamellosa, Christiania trentonensis, Resserella rogata, Linguilasma*, and "*Leptaena charlottae*"; upper part silicified	3	6
15. Limestone, cobbly, clayey, drab gray, contains "*Sowerbyella*" *pisum* and *Bimuria lamellosa*	5	
14. Shale, black, silty		3
13. Metabentonite, apricot buff		3
12. Limestone, drab gray, silty; upper half silicified	1	8
11. Shale, silty, black		3
10. Metabentonite, apricot buff; flaky partings of secondary calcite		2
9. Limestone, bluish gray; weathers to a spongy, channeled residue; contains *Christiania* and *Bimuria*	10	
8. Limestone, very argillaceous, contains *Eoplectodonta*	5	
Edinburg limestone (only upper part exposed; 200 feet)		
7. Limestone, drab gray, rather unevenly bedded	2	
6. Metabentonite, buff		2–4
5. Limestone, bluish gray, cobbly	2	6
4. Metabentonite, contains secondary calcite flakes		5
3. Limestone, dense, blocky		2½
2. Metabentonite		5
1. Limestone, black, fine-grained, evenly bedded, a 4-inch metabentonite 3 feet below top; *Lambeophyllum* and *Nidulites*	200+	

Fossils.—The following is a partial list of the fossils collected from the Oranda formation in the Shenandoah Valley:

Cystoids
- *Echinosphaerites aurantium* (Gyllenhahl)

Bryozoans
- *Batostoma* sp.
- *Hallopora* cf. *H. multitabulata* (Ulrich)

Brachiopods
- *Bimuria lamellosa* (Bassler) (Pl. 3, figs. 29–32).
- *Christiania trentonensis* Ruedemann
- *Eoplectodonta alternata* (Butts) (Pl. 3, figs. 26–28)
- "*Leptaena charlottae*" Winchell and Schuchert
- *Leptaena* sp.
- "*Leptobolus ovalis*" Bassler
- *Lingulasma* sp.
- *Oxoplecia simulatrix* (Bassler)
- *Orthambonites* sp.
- *Parastrophina* sp.
- *Resserella rogata* (Sardeson)
- *Reuschella "edsoni"* (Bassler) (Pl. 3, figs. 33–34)
- "*Sowerbyella*" *pisum* (Ruedemann)
- "*Strophomena*" *sculpturatus* Bassler

Age and correlation.—Through the occurrence of *Reuschella "edsoni,"* the Oranda is linked with the basal (Shoreham) member of the Sherman Fall limestone of the Trenton of New York. The Oranda formation also corresponds to the "*Christiania*" [*Bimuria*] bed of the Chambersburg limestone of southern Pennsylvania. The southern limits of the formation in Virginia are not yet known. Possibly it is represented in the lower part of the thick succession of sandy shales which have been identified as Martinsburg in the central and southwestern parts of the Appalachian

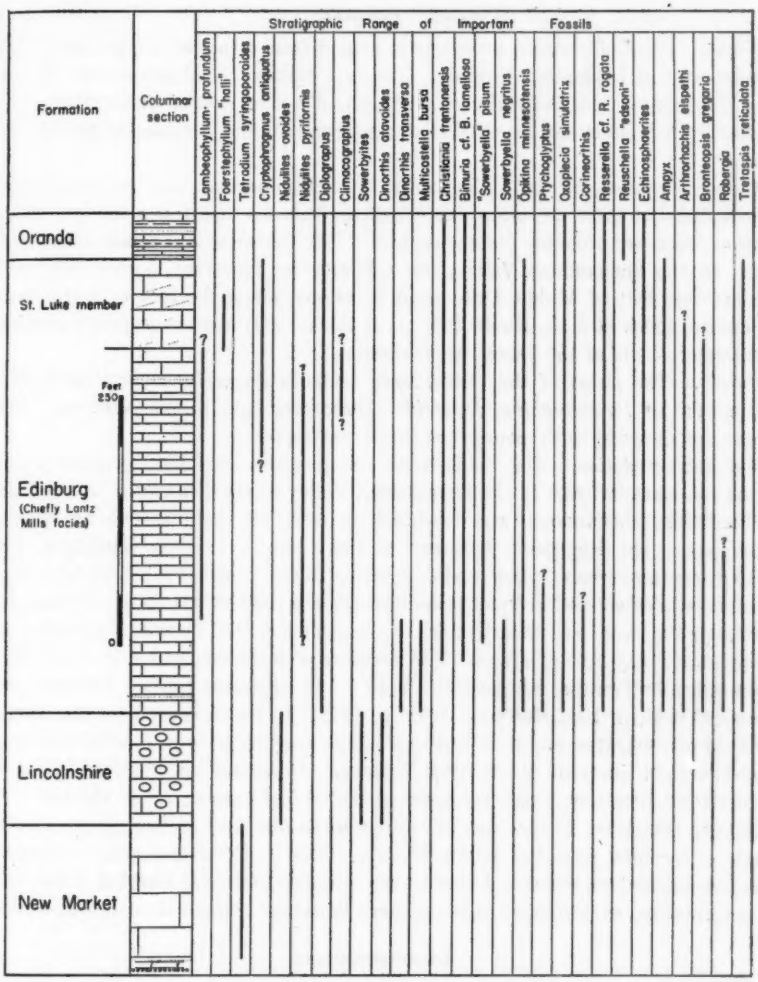

FIGURE 8.—*Columnar section of the lower Middle Ordovician formations in Shenandoah and Frederick counties, Virginia*

Valley in Virginia. This possibility is also worthy of consideration on the east side of the Massanutten syncline between Riverton and U. S. Route 250 east of Staunton. As already mentioned, there is evidence that the Martinsburg shaly, sandy beds are a megafacies of the Middle Ordovician, ranging as low stratigraphically as the base of the lower *Echinosphaerites* zone.

COLLIERSTOWN LIMESTONE

Name.—The Collierstown limestone is named from a hamlet along Collier Creek 8 miles west of Lexington, Virginia. The type section (Geologic section 42, units 52–53) is just north of State Highway 251, about 2 miles east of Collierstown. The Collierstown is underlain by the Edinburg formation and overlain by the Martinsburg.

Lithology.—Most of the Collierstown is shell limestone and medium-grained calcarenite, but there are intercalated buff argillaceous limestones and buff shales, some of which are probably metabentonites. The thickness is generally less than 75 feet. In the Shenandoah Valley, the Collierstown limestone occurs only in the westernmost belt of Middle Ordovician limestone, along the foot of Little North Mountain, south of U. S. Route 250. It is thicker and more widespread in middle and western belts of the James River district.

Fossils.—The fauna of the Collierstown includes *Zygospira recurvirostris* (Hall) and species of *Parastrophina, Doleroides, Cyclospira,* and *Rafinesquina* s.s. Some layers are crowded with poorly preserved gastropods.

Age and correlation.—The Collierstown occupies the same stratigraphic position in the southwestern part of the Shenandoah Valley as the *Reuschella "edsoni"* zone of Frederick, Shenandoah, and Rockingham counties, and the two are possibly equivalent. The Eggleston limestone in Lee County, Virginia (Huffman, 1945, p. 160), contains many of the fossils occurring in the Collierstown limestone of the Shenandoah Valley and in the Tyrone limestone of the Central Basin of Tennessee. Although they are not underlain by the same beds, the Tyrone, Eggleston, and Collierstown may be equivalent. The presence of *Rafinesquina* s.s. in the Collierstown indicates Trenton, and both the Tyrone and Eggleston contain Trenton fossils (Cooper, 1944, p. 103; Huffman, 1945, p. 173). Being succeeded by the *Sinuites* beds (Martinsburg) of middle Sherman Fall age, the Collierstown is within the Rockland-Shoreham interval of the type Trenton. It should be mentioned that the Collierstown limestone is not the same as the 60-foot calcarenite at the top of the Edinburg formation in the eastern and southern environs of Lexington, Virginia. That calcarenite contains *Foerstephyllum "halli", Dystactospongia, Lichenaria,* and *Lambeophyllum,* which link it with the St. Luke limestone member of the Edinburg formation, as developed in the western limestone belts of Shenandoah County.

UNCONFORMITIES

A marked disconformity at the top of the Beekmantown is indicated by: (1) the absence of typical Chazy (type Lenoir) fossils in the succeeding beds, except in a few localities where the typical Lenoir brachiopod, *Rostricellula pristina,* occurs below the "Mosheim" beds of the New Market limestone; (2) by considerable local variations in thickness and the local absence of the New Market limestone; and (3) by conglomeratic beds at the base of the New Market in many localities. The Lincolnshire and New Market are unconformable where the Whistle Creek limestone is absent. Locally, where the Lincolnshire directly overlies the Beekmantown, no New Market or Whistle Creek sediments accumulated.

In the section 2 miles southwest of Marion, Pennsylvania, the New Market lime-

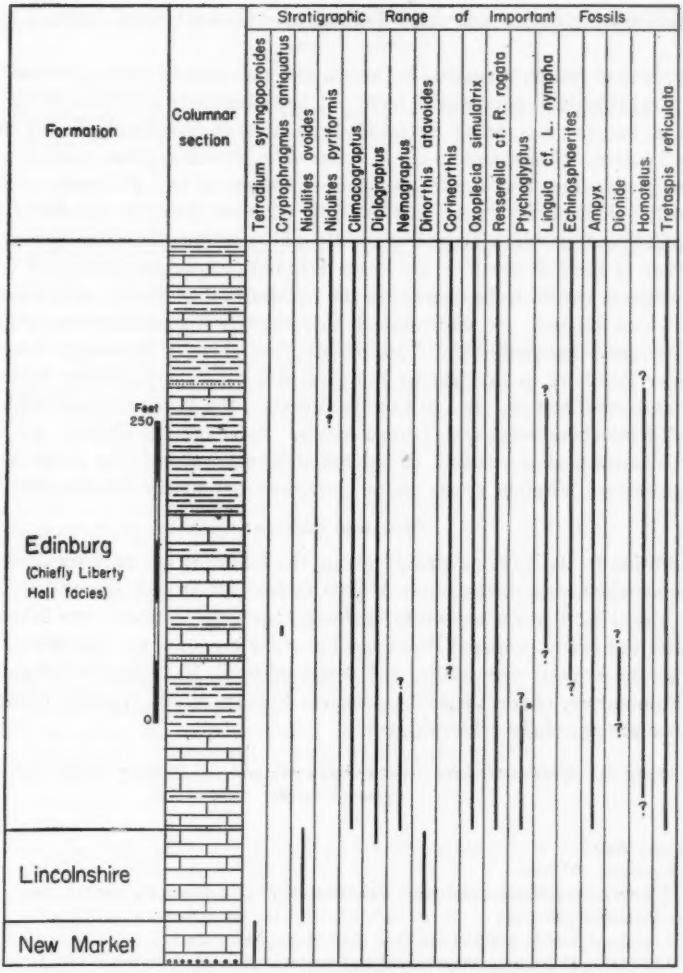

FIGURE 9.—*Columnar section of the lower Middle Ordovician formations in Clarke, Warren, Page, and eastern Rockingham counties*

stone (Geologic section 4, unit 1) is overlain by nearly 1000 feet of limestone older than the Edinburg or basal Chambersburg. The great changes in thickness and character of these limestones southward toward Virginia may include wedging out of much of the thick succession observed near Marion. The absence of *Tetradium cellulosum* and calcilutite just below the lower *Echinosphaerites* beds of Virginia suggests that the 358-foot succession of *Tetradium cellulosum*-bearing limestones southwest of Marion pinches out before reaching Virginia, but possibly the cherty

Lincolnshire represents a part of the *Tetradium cellulosum* beds of southern Pennsylvania.

There is some reason to regard the Oranda and underlying Edinburg as unconformable. Rockland-Hull equivalents have not been certainly identified in the upper Edinburg, and the succeeding *Reuschella* beds seem unmistakeably linked with the middle Trenton. *Receptaculites* cf. *R. occidentalis*, *Foerstephyllum "halli," Lambeophyllum profundum*, and *Cryptophragmus*—common in the Edinburg in western belts of the Shenandoah Valley—are listed by Okulitch (1939, p. 335–337) from the Coboconk limestone which Kay (1937, p. 256–257) identifies as lower Trenton. The magnitude of the hiatus at the top of the Edinburg cannot be determined until the relative ages of the St. Luke member of the Edinburg, the Oranda, and Collierstown have been established. In southwestern Virginia, the Witten limestone, containing *Cryptophragmus antiquatus* and *Camarocladia* and thereby seemingly linked with the upper Edinburg, is overlain by the Moccasin red beds which the writers now regard as lower Trenton. In Lee County, Virginia, the Moccasin is succeeded by a zone with metabentonites and Tyrone fossils. Although the Tyrone and Oranda and Collierstown may possibly be approximate equivalents, the thick Moccasin of southwestern Virginia seems to be unrepresented in the Shenandoah Valley.

GEOLOGIC SECTIONS

In addition to the sections already given, the following are representative of the various developments of the lower Middle Ordovician in the Shenandoah Valley. A few critical sections farther south, including the type section of the Murat limestone and the newly proposed Botetourt limestone member, are also given. Practically all the sections were studied and measured by B. N. Cooper in company with R. S. Edmundson, of the Virginia Geological Survey, whose friendly counsel and assistance are gratefully acknowledged.

Geologic section 15.—Middle Ordovician limestone half a mile east of U. S. Route 11, near Rest, Frederick County, Virginia

	Thickness Feet
Martinsburg shale	
Oranda formation (30 feet)	
9. Limestone, argillaceous, drab gray; with intercalated thin siltstones; poorly exposed.	30
Edinburg limestone (398 feet)	
8. Limestone, cobbly, argillaceous, dark gray (Lantz Mill facies)	95
7. Limestone, bluish gray, clayey, nodular; contains *Nidulites pyriformis* and *Lambeophyllum profundum*	108
6. Limestone, black, even-bedded (Liberty Hall facies)	69
5. Limestone, mostly nodular to cobbly (Lantz Mills facies), but contains thin zones of even-bedded black limestone (Liberty Hall facies); sparse *Nidulites* and *Lambeophyllum* throughout	68
4. Limestone, nodular to cobbly; contains a few beds crowded with *Echinosphaerites aurantium*	58
Lincolnshire limestone (216 feet)	
3. Limestone, medium gray, granular, sparsely cherty; mostly covered	98
New Market limestone (143 feet)	
2. Calcilutite, compact, light gray	118
1. Calcilutite, striped; contains impure drab-gray layers	25
Beekmantown dolomite	

Geologic section 16.—Middle Ordovician limestone east of U. S. Route 11, near Vaucluse, Frederick County, Virginia

	Thickness Feet
Martinsburg shale	
Oranda formation (25 feet)	
11. Siltstone and shaly limestone; brownish gray to buff gray; contains "*Sowerbyella*" *pisum*, *Christiania* sp., and *Eoplectodonta* sp.	25
Edinburg formation (522 feet)	
10. Limestone, earthy, cobbly, drab gray	10
9. Limestone, bluish gray, cobbly, contains *Nidulites* and *Lambeophyllum* (Lantz Mills facies)	75
8. Limestone, dense, black, even-bedded; contains *Nidulites* and *Lambeophyllum* (Liberty Hall facies)	256
7. Limestone, cobbly to nodular, drab gray; *Nidulites* near top and *Echinosphaerites* near the base (Lantz Mills facies)	59
6. Limestone, cobbly, clayey, drab gray; contains sparse *Lambeophyllum* near top and *Chasmatopora* sp. (Lantz Mills facies)	41
5. Covered interval; few showings of black slabby to cobbly limestone	79
4. Siltstone, shaly, poorly exposed; yellowish clayey laminae above and below	2
Lincolnshire limestone (118 feet)	
3. Limestone, granular, cherty, dark bluish gray	106
New Market limestone (135 feet)	
2. Calcilutite, dove gray, dense, pure, thick-bedded	80
1. Calcilutite, dove gray, thinner-bedded	57
Beekmantown dolomite	

Geologic section 17.—Middle Ordovician limestones 500 feet south of State Highway 274 and 1.7 miles S. 10° W. of Wadesville, Clarke County, Virginia

	Thickness Feet
Oranda formation	
Edinburg limestone (552 feet)	
17. Limestone, thin-bedded, dark gray, weathers bluish gray; partings of buff clay; contains *Nidulites* and *Christiania* (Lantz Mills facies)	85–90
16. Siltstone, buff, shaly; contains *Climacograptus*	3
15. Limestone, shaly to cobbly, not fully exposed (Lantz Mills facies)	16
14. Siltstone, buff to brown, shaly at the base	8½
13. Metabentonite, buff	½
12. Chert	¼
11. Limestone, black, cobbly toward the base; thin shaly partings define the bedding; abundant *Nidulites* (Lantz Mills facies)	20
10. Limestone, dense, black, slabby, with partings of black shale; contains layer crowded with *Homotelus* and *Lonchodomas* (Liberty Hall facies)	125
9. Limestone, buff weathering, very cobbly (Lantz Mills facies)	35
8. Limestone, dense, black, even-bedded; partings of black shale (Liberty Hall facies)	46
7. Siltstone, shaly, weathers reddish brown to brownish gray; contains *Resserella* cf. *R. rogata*	10–15
6. Limestone, fine-grained, cobbly, shaly partings; *Echinosphaerites* at the base and *Cryptophragmus antiquatus*[2] below the top (Lantz Mills facies)	47
5. Limestone, fine-grained, dense, black; *Homotelus* at the base (Liberty Hall facies)	60
4. Limestone, fine-grained, black, poorly exposed (Liberty Hall facies)	86
Lincolnshire limestone	
3. Limestone, dark bluish gray, granular, sparsely cherty; many layers crowded with *Girvanella*	58

[2] This *Cryptophragmus* although actually in a loose cobble could not have been transported because it occurred on a low knob. It was essentially in place, having merely been loosened as many of the cobbles are. A piece of the matrix of the *Cryptophragmus*-bearing cobble was digested in acid and yielded silicified fossils, including *Remopleurides*, which occur at the horizon where the cobble was found.

	Thickness Feet
New Market limestone	
2. Calcilutite, dove gray, even-bedded, pure	39
1. Calcilutite, impure; grades downward into limestone-pebble conglomerate at the base	29
Beekmantown dolomite	

Geologic section 18.—Middle Ordovician formations in the vicinity of Riverton, Warren County, Virginia

	Thickness Feet
Martinsburg formation (lower part only)	
6. Shale, black, much of it with fracture cleavage, well exposed along U. S. Route 522 north of Riverton bridge across the North Fork of Shenandoah River	150+
Beds of uncertain age; either Oranda or basal Martinsburg	
5. Sandstone, coarse-grained, argillaceous, arkosic; contains granulated remains of fossils, including *Diplograptus* sp., *Cryptolithus* sp., *Resserella*, and linguloids; fully exposed along north bank of Crooked Run, just east of U. S. Highway 522 bridge, near Riverton	8
Edinburg formation (435 feet)	
4. Limestone, cobbly, dense, black; contains *Corineorthis* and *Resserella*; exposed along abandoned right-of-way of U. S. Route 522, between Crooked Run and Riverton bridge	35
3. Limestone, slabby, black, with minor intercalations of shale; not fully exposed; repeated by folding, as shown along the north bluff of Shenandoah River east of the Riverton bridge; also exposed along U. S. Route 522 north of Crooked Run and west of highway junction with Road 655, 1.5 miles northeast of Riverton. Contains numerous graptolites and *Lingula* cf. *L. nympha*	400
Lincolnshire limestone (25–30 feet)	
2. Limestone, dark bluish gray, granular, very little chert; well exposed in the quarry of the Riverton Lime Co., and also along Road 655 about 0.25 mile east of U. S. Route 522, north of Riverton	20–30
New Market limestone (25–40 feet)	
1. Calcilutite, dove gray, slightly thinner-bedded and more impure toward the base; well exposed between U. S. Route 522 and Road 655 and south along the strike in the quarries of the Riverton Lime Co.	25–40
Beekmantown dolomite	

Geologic section 19.—Middle Ordovician limestones along and near the Southern Railroad, Strasburg Junction, Shenandoah County, Virginia

	Thickness Feet
Oranda formation	
Edinburg limestone (387 feet)	
21. Limestone; contains *Nidulites*, *Sowerbyella*, and *Lambeophyllum*; mostly covered	275+
20. Limestone, very clayey, partings of crumbly mudrock; limy beds weather in hourglass pillars; contains *Dinorthis transversa* and *Oxoplecia* cf. *O. simulatrix* (Lantz Mills facies)	25
19. Limestone, cobbly, thin-bedded, clayey, weathers buff; contains *Dinorthis transversa*, *Oxoplecia* cf. *O. simulatrix*, a large species of *Corineorthis*, and *Resserella* cf. *R. rogata*; *Echinosphaerites* 5 feet above the base (Lantz Mills facies)	35
18. Limestone, nodular, clayey, weathers buff; contains *Resserella*, *Cyrtonotella*, *Dinorthis* cf. *D. transversa*, *Sowerbyella*, *Öpikina*, *Ptychoglyptus*, *Orthambonites*, *Christiania*, *Eoharpes*, *Tretaspis*, *Homotelus simplex*, *Ceraurus pleurexanthemus*, and *Echinosphaerites aurantium* (Lantz Mills facies)	35
17. Limestone, coarsely granular, contains *Ampyxina* and *Bronteopsis* (Liberty Hall facies, resembles Butts' Whitesburg)	10
16. Limestone, fine-grained, clayey, dense, weathers buff (Liberty Hall facies)	7

	Thickness Feet
Lincolnshire limestone (179 feet)	
15. Limestone, thin-bedded, dark gray	11
14. Limestone, dense, black, cherty	64
13. Limestone, medium-grained, crowded with bryozoans; contains thin partings and intercalated beds of coarse-grained limestone full of *Girvanella*	4
12. Calcarenite, coarse-grained, cross-laminated; abundant *Girvanella*	5½
11. Limestone, medium-grained, dark gray; contains lenses of *Girvanella*-bearing calcarenite	3½
10. Calcarenite, cross-laminated, sparsely cherty	2½
9. Limestone, light gray, granular, sparsely cherty; contains *Rhinidictya* sp., *Sowerbyites* cf. *S. triseptatus*, *Dinorthis atavoides*, *Multicostella saffordi*, *Hesperorthis* cf. *H. tricenaria*, and *Maclurites* sp.	8¾
8. Limestone, dark gray, very cherty	1½
7. Limestone, light gray, cherty; contains lenses of calcarenite with *Girvanella*	3½
6. Limestone, dark gray, cherty	1½
5. Limestone, light gray, with lenses of *Girvanella*	47
4. Limestone, light gray, granular, sparsely cherty	19
3. Limestone, granular, thin-bedded, no chert	8
New Market limestone (measured east of Powhatan quarry; 162 feet)	
2. Calcilutite, dove gray, pure	133
1. Calcilutite, dove gray, thinner-bedded	29
Beekmantown dolomite	

Geologic section 20.—Middle Ordovician limestones along Tumbling Run, southwest of Strasburg, Shenandoah County, Virginia

	Thickness Feet	Thickness Inches
Oranda formation (50 feet)		
22. Limestone, shale, and siltstone; exposed along U. S. Route 11 about 300 yards north of Tumbling Run; very fossiliferous; contains *Lingulasma* sp., *Ptychoglyptus* sp., *"Sowerbyella" pisum*, *Bimuria*, *Oxoplecia simulatrix*, *Christiania trentonensis*, *Eoplectodonta alternata*, and *Reuschella "edsoni"*	50	
Edinburg limestone (530 feet)		
21. Limestone, crumbly, cobbly, buff gray, contains *Camarocladia* (Lantz Mills facies)	40	
20. Limestone, dark gray, dense, slabby to cobbly; contains *Nidulites* and *Lambeophyllum* (Lantz Mills facies)	200	
19. Limestone, dense, black, even-bedded; contains *Nidulites* and *Lambeophyllum* (Liberty Hall facies)	64	
18. Limestone, clayey, shaly, cobbly; contains *Nidulites* and *Lambeophyllum* (Lantz Mills facies)	26	
17. Limestone, medium-bedded, slabby, black (Liberty Hall facies)	22	
16. Limestone, very clayey, nodular (Lantz Mills facies)	9	
15. Limestone, dense, black, partings of black shale (Liberty Hall facies)	14	
14. Limestone, nodular to cobbly; contains *Nidulites* and *Lambeophyllum* (Lantz Mills facies)	26	
13. Limestone, dense, black, slabby; contains *Arthrorhachis*, *Robergia*, and *Bronteopsis*; *Nidulites* also plentiful but none below this unit (Liberty Hall facies)	45	
12. Limestone, argillaceous, cobbly; contains *Dinorthis* cf. *D. transversa*, *Resserella* cf. *R. rogata*, and a large *Corineorthis* (Lantz Mills facies)	20	
11. Limestone, nodular, buff, shaly; contains *Echinosphaerites aurantium*, *Chasmatopora "sublaxa,"* *Öpikina* cf. *Ö. "minnesotensis,"* *Homotelus simplex*, *Oxoplecia* sp., *Resserella* cf. *R. rogata*, *Christiania* sp., *Sowerbyella* sp. (Lantz Mills facies)	33	

	Thickness Feet	Thickness Inches
10. Limestone, granular, good ledge maker (Liberty Hall facies)	9	
9. Limestone, cobbly, buff; bright-buff shaly partings (Lantz Mills facies)	3	3
8. Siltstone, brownish buff, shaly in lower part	2	9½
7. Metabentonite, sheared, buff		10
6. Chert		1
5. Limestone, cobbly, several clayey partings which are probably metabentonitic (Lantz Mills facies)	7	
4. Limestone, irregularly bedded, medium-to coarse-grained (Liberty Hall facies, may be unit 17 of Geologic section 19)	7	4
3. Metabentonite, buff		8½
Lincolnshire limestone (132 feet)		
2. Limestone, mainly cherty, detailed description in Geologic section 8	132	
New Market limestone (55 feet)		
1. Calcilutite, dense, medium-bedded, crowded with *Tetradium syringoporoides*; base exposed in stream bed beneath bridge	55	
Beekmantown dolomite		

Geologic section 21.—Middle Ordovician limestones 500 feet north of Road 721, 0.3 mile east of U. S. Route 11 and about 1.5 miles south of Woodstock, Virginia

	Thickness Feet
Martinsburg formation	
Oranda formation (45 feet)	
7. Mudrock, silty, drab gray; contains a few thin beds of siltstone; not fully exposed; contains *Resserella* cf. *R. rogata*, *Eoplectodonta alternata*, *Reuschella "edsoni,"* *Bimuria lamellosa*, *Parastrophina* sp., *Christiania trentonensis*, *Oxoplecia simulatrix*, *Ptychopleurella* sp., and *Echinosphaerites* cf. *E. aurantium*	35
Edinburg limestone (510 feet)	
6. Limestone, black, medium-bedded; contains intercalated light- to medium-gray calcarenites with *Camarocladia*, numerous *Cryptophragmus antiquatus*, *Subulites*, *Maclurites*, and other gastropods; main bed with *Cryptophragmus* is 70 feet below the Oranda	86
5. Covered	26
4. Limestone, dark gray, cobbly to slabby, poorly exposed	27
3. Limestone, poorly exposed, slabby, dark gray, contains several beds crowded with *Nidulites*; one bed with *Cryptophragmus* and *Nidulites* 27 feet above the base	143
2. Limestone, mostly covered, a few beds with *Lambeophyllum* and *Nidulites*	162
1. Limestone, mostly covered, cobbly, buff weathering	66
Lincolnshire limestone	

Geologic section 22.—Middle Ordovician limestones in the vicinity of Cedar Grove Church, 3.7 miles south of Mt. Jackson, near U. S. Route 11

	Thickness Feet
Oranda formation (25–30 feet)	
11. Mudrock and siltstone, brownish gray, shaly; also contains beds of metabentonite and cobbly limestone; *Bimuria lamellosa*, *"Sowerbyella" pisum*, *Resserella rogata*, *Reuschella "edsoni,"* and *Echinosphaerites*	25–30
Edinburg limestone (839 feet)	
10. Limestone, cobbly, shaly, buff weathering; with *Christiania* (Lantz Mills facies)	8
9. Limestone, medium-bedded, black, compact; numerous intercalated beds and thin zones of coarse-grained calcarenite with *Camarocladia*, *Cryptophragmus*, *Maclurites*	65
8. Limestone, medium-bedded, black, compact (Liberty Hall facies); contains *Nidulites*	38

	Thickness Feet
7. Limestone, black, compact (Liberty Hall facies)	62
6. Limestone, dense, black, medium-to thin-bedded; *Echinosphaerites* at the top (Liberty Hall facies)	76
5. Limestone, dense, black, fine-grained; *Ampyx* or *Lonchodomas*	45
4. Limestone, mainly cobbly to slabby, weathers drab gray; *Echinosphaerites* at the base	24
3. Limestone, cobbly (Lantz Mills facies)	33
2. Limestone, buff, cobbly; contains *Echinosphaerites* and *Lonchodomas*	13
1. Mainly covered; exposed beds are black limestone and shale (all Liberty Hall facies)	475
Lincolnshire limestone	

Geologic section 23.—Middle Ordovician limestones along State Highway 256, about 1½ miles N. 72° W of Broadway, Rockingham County, Virginia

	Thickness Feet
Edinburg limestone	
Lincolnshire limestone (182 feet)	
8. Limestone, dark gray, granular, cherty	100
7. Covered interval; black fossiliferous chert nodules in soil; contains *Dinorthis* cf. *D. atavoides*	82
New Market limestone (200 feet)	
6. Calcilutite, dove gray, medium-bedded	18
5. Limestone, dark gray, compact, no chert	7
4. Calcilutite, thin-bedded, impure; clayey partings	49
3. Covered	20
2. Calcilutite, ribbon-banded, with alternating partings of buff clayey limestone	43
1. Dolomite, drab buff to drab gray; breaks with conchoidal fracture; contains interbedded fine-grained dove-gray limestones; some layers straticulate; contains lenses of intraformational sliver breccia	63
Beekmantown dolomite	

Geologic section 24.—Middle Ordovician limestones 1.6 miles south of Bethel Church and 6 miles east of Harrisonburg

	Thickness Feet
Martinsburg formation (contact approximate)	
Edinburg formation (all Liberty Hall facies; 943 feet)	
11. Shale and limestone, black	210
10. Siltstone, rusty brown, friable; contains *Parastrophina* sp.	35
9. Limestone, dense, black, weathers bluish gray; contains trilobites	225
8. Limestone, thin-bedded, shaly; graptolites	142
7. Limestone black, medium-bedded, very little shale	70
6. Limestone, contains *Ptychoglyptus*, *Multicostella* cf. *M. bursa*, trinucleid trilobites	61
5. Shale, black with graptolites; contains intercalated platy black limestones	150
4. Limestone, thin-bedded to platy, black; contains trilobites	30
3. Botetourt limestone member, brownish weathering, coarse-grained, makes crest of ridge; contains "*Leptobolus ovalis*" Bassler	20
Lincolnshire limestone (40 feet)	
2. Limestone, dark bluish gray, cherty	40
New Market limestone (65 feet)	
1. Calcilutite, medium-to thick-bedded; dove gray to black	65
Beekmantown dolomite	

Geologic section 25.—Middle Ordovician limestone 250 yards west of State Highway 12 and 1 mile north of the intersection with Road 607, Warren County, Virginia

	Thickness Feet
Martinsburg shale	
Edinburg limestone (all of Liberty Hall facies; 432 feet)	
10. Shale, black, weathers buff; contains few black limestone beds near the top	188
9. Shale and limestone, black; transition zone with thickness and number of shaly zones increasing upward	184
8. Limestone, increasingly thinner-bedded toward base; very few partings of black shale	47
7. Limestone and shale, interbedded, black	9
6. Shale, black	14
Lincolnshire limestone (49 feet)	
5. Limestone, black, fine-grained, nodular	14
4. Limestone, cherty, dark gray, granular	27
3. Limestone, noncherty, medium-grained	8
New Market limestone (6½ feet)	
2. Calcilutite, fine-grained, dove gray, thin-bedded	5½
1. Conglomerate, lenticular; pebbles of dolomite and limestone	1
Beekmantown dolomite	

Geologic section 26.—Middle Ordovician limestones at Bixler bridge across South Fork of Shenandoah River, 3 miles N. 30° W. of Luray, Virginia

	Thickness Feet
Edinburg formation (all Liberty Hall facies)	
Lincolnshire limestone (134 feet)	
4. Limestone, dark bluish gray, nodular, cherty, stained reddish brown along bedding	31
3. Limestone, dark gray, cherty	45
2. Limestone, dark bluish gray, fine-grained, cherty near base and at the top	58
New Market limestone (3 feet)	
1. Conglomerate; dolomitic matrix, pebbles of chert and dolomite	3
Beekmantown dolomite	

Geologic section 27.—Middle Ordovician limestone about 0.25 mile N. 50° W. of Leaksville and 5 miles S. 53° W. of Luray, Virginia

	Thickness Feet
Edinburg formation (all Liberty Hall facies)	
Lincolnshire limestone (15 feet)	
9. Limestone, gray, granular; contains *Nidulites ovoides* and large cephalopods	15+
New Market limestone (224 feet)	
8. Calcilutite, dove gray	10
7. Limestone, dark bluish gray, algal structures, reddish blotches	4
6. Calcilutite, impure	1½
5. Calcilutite, dove gray, relatively pure	9
4. Limestone, impure, fine-grained, striped	9
3. Limestone, light gray to drab gray, striped	12
2. Calcilutite, dove gray	4
1. Boulder- and cobble-conglomerates; composed of dolomite and limestone pebbles, and a matrix of clastic dolomite and fine-grained limestone; age of beds uncertain but tentatively referred to the New Market; apparently a narrow channel deposit, for boulder beds cannot be followed more than 200 feet along the strike	175
Beekmantown limestone and dolomite	

Geologic section 28.—Middle Ordovician limestones along U. S. Route 33, about 5 miles southeast of Harrisonburg, Rockingham County, Virginia

	Thickness Feet
Edinburg formation (all of Liberty Hall facies; 833 feet)	
14. Covered interval, mostly black shale; thickness indeterminate	—
13. Shale and limestone, black, platy to slabby; a thick metabentonite about 50 feet above the base; *Robergia* 10 feet, and *Cryptolithus* 97 feet, above the base	150
12. Limestone, black, nodular; contains thin partings of black shale with *Diplograptus*, *Climacograptus*, and *Dicellograptus*	100
11. Siltstone, black, sandy; contains abundant *Resserella* cf. *R. rogata*	4
10. Shale, black, fissile; a few intercalated limy beds; contains graptolites	70
9. Shale and shaly limestone; large *Climacograptus* in top beds, along farm lane	165
8. Limestone, black, medium-bedded, dense	134
7. Shale and shaly limestone, black, platy to slabby; Botetourt limestone member very thin and poorly exposed at base	210
Lincolnshire limestone (65 feet)	
6. Limestone, dark gray, irregular-bedded; pinkish streaks along the bedding	15
5. Calcilutite, dove-gray, medium-bedded	27
4. Limestone, medium-bedded, dark gray	23
New Market limestone (upper boundary uncertain; 78 feet)	
3. Calcilutite, compact, dove gray	57
2. Limestone, dark gray, finely granular; reddish streaks along the bedding; sparsely cherty	7
1. Calcilutite, light gray	14
Beekmantown dolomite	

Geologic section 29.—Middle Ordovician limestones along State Highway 12, about 800 feet east of its intersection with U. S. Route 33, near Montevideo, Rockingham County, Virginia

	Thickness Feet
Edinburg formation (all of Liberty Hall facies)	
Lincolnshire limestone (69 feet)	
6. Limestone, dark gray, fine-grained, cherty	69
New Market limestone (72 feet)	
5. Calcilutite, dove gray, medium-bedded	14
4. Calcilutite, buff gray, clayey	2
3. Calcarenite, medium gray, thin-bedded	42
2. Limestone, irregular texture, mainly fine-grained	6
1. Limestone, coarse-grained, medium gray; fine-grained limestones intercalated near the base; *Rostricellula pristina*	8
Beekmantown dolomite (top irregular)	

Geologic section 30.—Middle Ordovician limestones half a mile south of the intersection of alternate U. S. Route 11 and U. S. Route 11, in the north environs of Staunton, Augusta County, Virginia

	Thickness Feet
Edinburg formation (all Liberty Hall facies; 260+ feet)	
6. Shale, black, not very limy; thickness undetermined	—
5. Shale, limy, black, weathers yellowish brown	100
4. Limestone, dense, black	150
3. Botetourt limestone member; granular, irregularly bedded; contains many fragments of trilobites	10
Lincolnshire limestone (100 feet)	
2. Limestone, fine to medium-grained, gray, cherty; contains *Dinorthis atavoides*	100
New Market limestone (75 feet)	
1. Calcilutite, dark gray to dove gray; thoroughly fractured	75
Beekmantown dolomite	

Geologic section 31.—Middle Ordovician limestones along U. S. Route 250 about 3½ miles west of Staunton, near junction with State Highway 56

	Thickness Feet	In.
Edinburg formation (all Liberty Hall facies)		
Lincolnshire limestone (134 feet)		
6. Covered interval; few showings of black cherty limestone	38	
5. Limestone, cherty, dark gray, pinkish streaks along the bedding; contains *Dinorthis atavoides*, *Multicostella* sp., *Mimella* sp., and ribbon bryozoans	96	
Whistle Creek limestone		
4. Limestone, granular to fine-grained, light gray, contains *Multicostella saffordi* *Hesperorthis* sp., and *Girvanella* sp.	87	
New Market limestone (47 feet)		
3. Calcilutite, gray to drab gray, clayey partings, relatively impure	44	
2. Mudrock, reddish brown, conchoidal fracture; contains fragments of chert and dolomite	2	6
1. Mudrock, dolomitic, shaly, reddish brown		6
Beekmantown dolomite		

Geologic section 32.—Middle Ordovician limestone just east of Chesapeake Western Railroad, northeast environs of Staunton, Augusta County, Virginia

	Thickness Feet
Edinburg formation (all Liberty Hall facies; 310 feet)	
8. Shale, black, contains Normanskill graptolites; thickness indeterminate	—
7. Limestone and shale, black, platy to slabby, thickness estimated	150
6. Shale, black, fissile, slaty cleavage; contains few thin limestones near the base	150
5. Botetourt limestone member, granular, cobbly to shaly	10
Lincolnshire limestone (120± feet)	
4. Limestone, black, granular; very cherty	60
3. Calcarenite, coarse-grained, texture very irregular, contains large algal masses, very pure (Murat calcarenite facies)	60
Whistle Creek limestone	
2. Limestone, drab gray, very argillaceous; pinches out locally	0–20
New Market limestone (84 feet)	
1. Calcilutite, thin-bedded, thoroughly fractured	84
Beekmantown dolomite	

Geologic section 33.—Middle Ordovician limestones in the east end of the Staunton Lime Company Quarry, 2.5 miles northeast of Staunton, Virginia

	Thickness Feet
Edinburg formation (all Liberty Hall facies)	
Lincolnshire limestone (40 feet)	
4. Limestone, very cherty, thin, shaly	40
New Market limestone (60 feet)	
3. Calcilutite, dove gray, medium-bedded	25
2. Limestone, dark gray, nodular, impure	10
1. Calcarenite, light gray, partly cross-laminated, basal portion fills cavities in the underlying Beekmantown and contains *Rostricellula pristina*; lower contact very irregular (units 1 and 2 absent in west end of quarry)	20±
Beekmantown dolomite	

Geologic section 34.—Middle Ordovician limestones in an abandoned quarry a quarter of a mile east of the junction of Roads 608 and 652, about 6.7 miles S. 21°E. of Staunton, Virginia

	Thickness Feet
Edinburg formation (all Liberty Hall facies)	
Lincolnshire limestone (117 feet)	
6. Limestone, dark gray, nodular, medium-grained, very cherty; contains *Dinorthis atavoides*; top poorly exposed	75
5. Calcarenite, gray, coarse-grained (Murat calcarenite facies)	6
4. Limestone, medium-grained, dark gray, nodular, sparsely cherty; contains *Sowerbyites* and *Clitambonites*	16
3. Calcarenite, coarse-grained, thick-bedded, white (Murat calcarenite facies)	20
Whistle Creek limestone	
2. Limestone, dark gray, very cherty; contains intercalated thin beds of medium-grained limestone; contains *Hesperorthis*	30
New Market limestone (60 feet)	
1. Limestone, mostly dove-gray calcilutite, but contains clastic layers representing reworked lime muds	60
Beekmantown dolomite	

Geologic section 35.—Middle Ordovician limestones just west of Road 652, about 1.8 miles northeast of the junction of State Highway 12 and Road 652 and 6.4 miles S. 5° E. of Staunton

	Thickness Feet
Edinburg formation (all Liberty Hall facies)	
Lincolnshire limestone (199 feet)	
7. Limestone, dark gray, granular, cherty	46
6. Calcarenite, light gray, coarse-grained, thick-bedded (Murat calcarenite facies)	112
5. Calcarenite, medium- to coarse-grained, medium gray (Murat calcarenite facies)	41
Whistle Creek limestone	
4. Limestone, dark gray, nodular, very cherty; contains *Mimella* and *Camerella*	56
New Market limestone (117½ feet)	
3. Calcilutite, light gray, medium-bedded	51
2. Limestone, dark gray, impure, nodular	6½
1. Calcilutite, dove gray, compact; base not exposed	60
Beekmantown dolomite	

Geologic section 36.—Middle Ordovician limestones west of Road 652, 6.8 miles due south of Staunton and a mile northeast of the junction of Road 652 and State Highway 12

	Thickness Feet
Edinburg formation (all Liberty Hall facies)	
Lincolnshire limestone (206 feet)	
8. Limestone, dark gray, cherty; mostly covered	30±
7. Calcarenite, coarse-grained, medium to light gray, thick-bedded (Murat calcarenite facies)	176
Whistle Creek limestone	
6. Limestone, dark gray, cherty, nodular	69
New Market limestone (130 feet)	
5. Calcilutite, dove gray, contains a few very thin impure layers near the middle	130
Beekmantown formation (103 feet)	
4. Limestone, dolomitic	3
3. Calcilutite, pearl gray; typical Beekmantown limestone	29
2. Limestone, drab gray, dolomitic	7
1. Calcilutite, pearl gray; underlain by great thickness of Beekmantown dolomite and limestone	64

Geologic section 37.—Middle Ordovician limestones about 0.7 mile east of the intersection of U. S. Route 11 and Road 654, about 4.5 miles S. 5° W. of Staunton, Augusta County, Virginia

	Thickness Feet
Edinburg formation (all Liberty Hall facies)	
Lincolnshire limestone (68 feet)	
6. Limestone, dark gray, finely granular	25
5. Calcarenite, reefy structures, light gray, coarse-grained (Murat calcarenite facies)	18
4. Limestone, nodular, dark gray, cherty	25
New Market limestone (36½ feet)	
3. Calcilutite, medium-bedded, dove gray	16–23
2. Limestone, dark bluish gray, cherty	3½
1. Calcilutite, dove gray and buff striped; contains peculiar granular pinkish masses of limestone along fractures and joints	6–10
Beekmantown dolomite	

Geologic section 38.—Middle Ordovician limestones along Road 602, about 5.5 miles S. 82° W. of Middlebrook, Augusta County

	Thickness Feet
Botetourt limestone member	
6. Limestone, medium- to coarse-grained, light gray; weathers rusty brown and mealy	15
Lincolnshire limestone	
5. Limestone, dark bluish gray, medium-grained, very cherty; contains *Dinorthis atavoides* and *Sowerbyites triseptatus*	126
Five Oaks (?) limestone	
4. Calcilutite dove gray; contains *Tetradium syringoporoides*	5
Whistle Creek limestone	
3. Limestone, dark gray, very impure, thin-bedded; intercalated lenses and beds of blocky-weathering chert containing *Hesperorthis*, *Strophomena*, and *Dinorthis holdeni*	229
New Market limestone (69 feet)	
2. Calcilutite, dove gray to smoky gray, sparsely cherty; striped with buff argillaceous bands; contains *Tetradium syringoporoides*	14
1. Limestone, dove gray, fine-grained, contains many poorly preserved gastropods; transitional with underlying dolomite; base arbitrarily drawn at top of highest dolomite	55
Beekmantown formation	

Geologic section 39.—Middle Ordovician limestone at base of Little North Mountain, west of Road 602, near the Augusta-Rockbridge County line[a]

	Thickness Feet
Martinsburg formation	
Collierstown limestone	
8. Limestone, medium-grained, calarenitic; contains intercalated beds and partings of buff shale and golden-gray fine-grained limestone; fossils include *Doleroides*, *Zygospira*, and *Rafinesquina* s.s.	45
Edinburg formation (718 feet)	
7. Limestone, medium to dark gray, slabby to cobbly; weathers smoky gray; contains *Nidulites* and *Lambeophyllum*	40
6. Limestone, black, slabby, some beds weather buff; contains *Christiania*, *Resserella*, *Dinorthis transversa*, and *Echinosphaerites*	400±

[a] Units 1–3 measured at point 2.3 miles northeast of county line; units 3–8 measured at point 0.5 mile northeast of county line.

	Thickness Feet
5. Siltstone, dark brown, weathers mealy; contains *Homotelus* and fragments of a coarse-ribbed dinorthid	1–2.5
4. Buff shale, metabentonitic (?)	0.5
3. Limestone, drab gray to buff; weathers cobbly; contains *Echinosphaerites*, *Lambeophyllum*, *Resserella* cf. *R. rogata*, and *Sowerbyella* (Lantz Mills facies)	65
2. Limestone, black, compact, evenly bedded with partings of black shale (Liberty Hall facies)	150
1. Botetourt limestone member, dark gray, medium-grained, very impure; weathers rusty brown; contains *Bronteopsis* and *Resserella*	60
Lincolnshire limestone	

Geologic section 40.—Middle Ordovician limestone between Whistle Creek and U. S. Route 60, about 2 miles northwest of Lexington, Rockbridge County, Virginia

	Thickness Feet
Edinburg formation (1070 feet)	
13. Black shale and black limestone (Liberty Hall facies); thickness estimated	1000
12. Botetourt limestone member, dark gray to black-fine-grained, silty; contains *Echinosphaerites*, *Ptychoglyptus*, and *Bronteopsis gregaria*	70
Lincolnshire limestone (280 feet)	
11. Limestone, medium- to fine-grained, some layers cherty; contains *Dinorthis atavoides* and *Sowerbyites triseptatus*; exposed along south bluff along Whistle Creek about 1000 feet east of Road 669	60–65
10. Murat calcarenite facies, light gray, thick-bedded, very pure	70
9. Limestone, shaly, nodular, dark gray, sparsely cherty; contains sowerbyellid brachiopods and *Homotelus*	10
8. Murat calcarenite facies, light gray, thick-bedded, very pure	85
7. Limestone, dark gray, cobbly, impure, contains *Dinorthis*	5
6. Limestone, dark to medium gray, evenly-bedded, medium- to coarse-grained; contains *Dinorthis*	25
Whistle Creek limestone (82 feet)	
5. Limestone, dark bluish gray, irregularly bedded, with wavy siliceous partings; contains *Hesperorthis*	18
4. Limestone, medium- to fine-grained, very cherty, with shaly partings; contains *Hesperorthis*, *Camerella*, *Valcourea*, *Mimella*, and *Multicostella saffordi* (Butts, 1941, Pls. 73–74)	64
New Market limestone (measured just south of U. S. Route 60 and 250 feet east of bridge across Whistle Creek; 31 feet)	
3. Limestone, dove gray, fine-grained, rather impure	16
2. Limestone, bluish gray, medium-bedded, sparsely cherty	2
1. Limestone, bluish gray, thinly bedded, contains pebbles of chert near the base	13
Beekmantown dolomite	

Geologic section 41.—Middle Ordovician limestone just southeast of Road 670, about a mile northwest of Murat and 4 miles southwest of Lexington, Rockbridge County

	Thickness Feet
Edinburg formation (1000± feet)	
9. Limestone and shale, black, thickness undetermined; only basal part exposed (all Liberty Hall facies)	—
8. Botetourt limestone member, dark gray, impure, thin-bedded, cobbly, silty; contains *Bronteopsis* and *Ptychoglyptus*	44
Lincolnshire limestone (250 feet)	
7. Murat calcarenite facies, light gray, massive, cross-laminated, weathers in rounded spheroidal masses	215

	Thickness Feet
6. Limestone, dark bluish gray, cherty	1
5. Limestone, even-bedded, coarse-grained, calcarenitic	34
Whistle Creek limestone	
4. Limestone, dark gray, fine-grained, thin-bedded, with ropy siliceous partings; contains *Hesperorthis* fauna	65
New Market limestone (33 feet)	
3. Calcilutite, dove gray	10
2. Calcilutite, light gray, thin-bedded, cherty	5
1. Calcilutite, gray, irregularly bedded; contains intercalated beds of dark-gray cherty limestone; chert pebbles in the lowest layers	18
Beekmantown dolomite	

Geologic section 42.—Ordovician limestones along State Highway 251 about 6.5 miles S. 80° W. of Lexington and 2 miles east of Collierstown Post Office, Rockbridge County

	Thickness Feet
Martinsburg formation	
Collierstown limestone (58 feet)	
53. Calcarenite, medium-grained, even-bedded; intercalated beds and partings of buff shale and impure drab-gray limestone; contains *Zygospira recurvirostris, Doleroides, Parastrophina?*, and a few *Rafinesquina* s.s.	50
52. Limestone, nodular, argillaceous, weathers drab gray; contains intercalated calcarenites with many poorly preserved gastropods	8
Edinburg formation (695 feet)	
51. Limestone, black, fine-grained, dense, evenly bedded with partings of black shale which weathers buff (Liberty Hall facies)	25
50. Limestone, medium gray, weathers buff; a conspicuous ledge maker; repeated by a shallow syncline visible from the highway	20
49. Limestone, buff, very argillaceous, weathers cobbly; contains *Echinosphaerites, Dinorthis transversa, Christiania, Resserella* cf. *R. rogata, Sowerbyella, Ampyx*, and *Bronteopsis* in the lower 75–100 feet (Lantz Mills facies)	135
48. Limestone, black, compact, even-bedded; partings of black shale; upper 15 feet contains *Dinorthis transversa* (Liberty Hall facies)	55
47. Limestone, black, fine-grained, partings of black shale (Liberty Hall facies)	214
46. Limestone, dark gray, cobbly to slabby, weathers buff, contains *Resserella, Echinosphaerites*, and *Dinorthis transversa* (Lantz Mills facies)	41
45. Limestone, dark gray, slabby, contains great abundance of *Homotelus* and *Lonchodomas*, a few *Echinosphaerites* (intermediate between Liberty Hall and Lantz Mills facies)	57
44. Limestone, black, weathers buff and cobbly; contains *Lonchodomas, Glyptorthis*, and *Chasmatopora* (Lantz Mills facies)	12
43. Metabentonite, orange buff	0.2
42. Limestone, black, dense, evenly bedded, with partings of black shale; weathers slabby; contains *Lonchodomas* and *Homotelus* (Liberty Hall facies)	178
41. Botetourt limestone member, granular, impure, silty, contains *Echinosphaerites* and *Ptychoglyptus*	8
Lincolnshire limestone (235 feet)	
40. Limestone, dark gray, medium-bedded, cherty; contains *Dinorthis atavoides* and *Sowerbyites triseptatus*	87
39. Limestone, medium- to coarse-grained; weathers nodular but looks massive in fresh exposures	51
38. Limestone, medium gray, medium- to coarse-grained, calcarenitic	5
37. Murat calcarenite facies, light gray, cross-bedded	6

	Thickness Feet
36. Limestone, dark gray, nodular	11
35. Limestone, medium to dark gray, granular, calcarenitic	5
34. Murat calcarenite facies, light gray	5
33. Limestone, dark gray, granular, contains *Sowerbyites*	8
32. Murat calcarenite facies, light gray, cross-bedded	12
31. Limestone, dark gray, very impure, wavy-bedded, nodular	40
30. Murat calcarenite facies, coarse-grained, medium to light gray	5
Whistle Creek limestone	
29. Limestone, dark gray, rather fine-grained, very impure; lower half contains great abundance of chert; rock weathers to a mealy spongy residue; contains *Hesperorthis*, *Valcourea*, *Camerella*, and many bryozoans	165
New Market limestone (84.6 feet)	
28. Calcilutite, dove gray	3.5
27. Limestone, clastic-textured, fine-grained	3.7
26. Calcilutite, dove gray	2.0
25. Calcilutite, dove gray, thin-bedded, sparsely cherty	5.4
24. Limestone, medium gray, fine-grained, cherty	1.4
23. Limestone, dark gray, contains nodules of black chert	1.7
22. Calcilutite, medium gray, sparsely cherty	30.0
21. Limestone, dark gray, fine-grained	5.3
20. Calcilutite, dark gray, even-bedded, upper part reworked into a clastic limestone of similar color	1.8
19. Calcilutite, dark gray; contains nodules of black chert	4.5
18. Calcilutite, dark gray and drab gray mottled	4.0
17. Limestone, bluish gray, cherty	0.2
16. Calcilutite, blocky-bedded, wavy clay partings	4.4
15. Calcilutite, banded light bluish gray and buff gray	1.3
14. Calcilutite, dark gray, mottled, very argillaceous	12.0
13. Limestone, smoky gray, impure	0.6
12. Limestone, clastic	0.2
11. Shale, ash gray, mealy	0.2
10. Calcilutite, mottled gray and buff; contains gastropods and *Leperditia*	11.4
9. Limestone, dolomitic, weathers mealy and drab gray	1.0
8. Calcilutite, dark gray, laminated	1.6
7. Limestone, dark gray, impure, ribbon-banded; contains pyrite	2.4
6. Dolomite, drab gray, impure, clastic texture	1.7
5. Calcilutite, bluish gray, weathers buff	0.8
4. Conglomerate, gray, contains small pebbles of limestone, dolomite, and chert; weathers drab gray	
3. Calcilutite, dove gray; contains curly buff partings of buff argillaceous limestone; a few *Tetradium*	5.0
2. Limestone, dark gray, even-bedded	6.5
1. Conglomerate, contains pebbles of dolomite, limestone, and chert	2.0
Beekmantown dolomite	

Geologic section 43.—Middle Ordovician limestone, 0.5 mile south of Dunkard Church and 6.9 miles S. 80° W. of Natural Bridge, Rockbridge County

	Thickness Feet
Martinsburg formation	
Collierstown limestone	
12. Limestone, light gray, medium- to coarse-grained, calcarenitic; thin intercalations of siltstone, buff shale, and metabentonite; contains *Zygospira*, *Doleroides*, *Rafinesquina*, gastropods, and poorly preserved rhynchonellids	75

	Thickness Feet
Edinburg formation (556½ feet)	
11. Limestone, black, slabby to blocky (Liberty Hall facies)	83
10. Limestone, dark gray, slabby, contains *Cyclospira* (Liberty Hall facies)	21
9. Limestone, cobbly, buff gray (Lantz Mills facies); contains large dinorthid close to *Dinorthis transversa*	28
8. Limestone, black, cherty (Liberty Hall facies); contains *Sowerbyella* and *Echinosphaerites* at the base	54
7. Limestone, slabby, dark gray to black; contains thin shaly partings (Liberty Hall facies); contains *Echinosphaerites* near the base	83
6. Limestone, thin-bedded, shaly (Liberty Hall facies); *Echinosphaerites* near the base and in the middle	107
5. Shale, black, contains graptolites (Liberty Hall facies)	30
4. Limestone, black, slabby (Liberty Hall facies)	30
3. Botetourt limestone member (type section)	
c. Shale and limestone, deeply weathered to spongy residue; *Resserella* cf. *R. rogata* and many ostracodes	6½
b. Limestone, rusty brown, coarse-grained, contains a small species of *Oxoplecia*, a leptaenoid, and *Bronteopsis gregaria*	18½
a. Limestone, nodular, argillaceous, with thin partings of coarse-grained rusty-brown limestone; contains *Resserella*, *Bronteopsis*, *Echinosphaerites aurantium* (very abundant), *Receptaculites* sp., a large *Orthambonites*, *Multicostella bursa*, and *Sowerbyella negrita*	42
Lincolnshire and Whistle Creek limestones (250 feet)	
2. Limestone, dark bluish gray, nodular, cherty; contains many *Sowerbyites* and *Multicostella*	250
New Market limestone (20 feet)	
1. Calcilutite, dove gray, rather thin-bedded	20
Beekmantown dolomite	

SUMMARY OF CONCLUSIONS

Need for reclassification of the lower Middle Ordovician of the Shenandoah Valley is summarized as follows;

(1) Beds identified as Stones River in the northern Appalachian Valley are older than the Stones River of central Tennessee.

(2) The Stones River of southern Pennsylvania is possibly all younger than the New York Chazy.

(3) Most of Giles' Stones River limestone in Frederick County, including the 600 feet of "Murfreesboro" and 150 feet of "Ridley-Pierce," is Beekmantown dolomite.

(4) The upper 150 feet of a 358-foot succession of dove-gray calcilutite, 2 miles southwest of Marion, Franklin County, Pennsylvania, was originally placed in the Chambersburg and identified as a Lowville equivalent. The supposed Lowville beds are faunally and lithogenically related to the underlying 200 feet of calcilutite, which Stose and Ulrich made the upper division of the Stones River limestone. These arbitrary formation identifications have led to considerable confusion regarding the relative ages of the Stones River and Black River groups in the Appalachian region.

(5) Stose's Lowville beds at the base of the type Chambersburg do not correspond to the *Cryptophragmus*-bearing limestones identified as Lowville at Fort Loudon,

Dickey, and at a point 2 miles south of St. Thomas, Pennsylvania. The *Cryptophragmus*-bearing beds at these localities overlie the beds containing *Caryocystites*, whereas, in the type section of the Chambersburg, the so-called Lowville beds occur more than 300 feet below the horizon of *Caryocystites*.

(6) Confusion as to the age of the Chambersburg has arisen from identification of underlying beds as "Stones River" and "Lowville." Although the fossils in the 358-foot succession of calcilutite below the Chambersburg are definitely no older than Black River, they are not necessarily of Lowville age, as formerly supposed. Indeed, the "Lowville" of the Marion section is not the same as the much younger faunal zone, characterized by relatively abundant *Cryptophragmus*, which has been identified by Butts and others as Lowville in northwestern and southwestern Virginia.

(7) Butts' Mosheim of the Shenandoah Valley probably corresponds to the relatively thin calcilutite at the base of the "Stones River" limestone, 2 miles southwest of Marion, Pennsylvania. Precise equivalency of the Shenandoah Valley Mosheim to the type Mosheim of Tennessee has never been demonstrated. Near Staunton, Virginia, Butts' Mosheim is underlain by a clastic limestone containing *Rostricellula pristina*, a characteristic Chazy rhynchonellid found near the base of the type Lenoir of Tennessee.

(8) Butts' Lenoir in northern Virginia is apparently not represented in the Lenoir of the type locality. The *Dinorthis atavoides* zone occurs considerably above the beds with *bona fide* Lenoir fossils in the southern parts of the Appalachian Valley of Virginia.

(9) Coarse-grained limestones, representing a clastic facies of the typically cherty dark-gray *Dinorthis atavoides* zone, have been misinterpreted as younger than the "Lenoir" and misidentified as Holston.

(10) The lower *Echinosphaerites* and *Nidulites* zones are laterally continuous with a much thicker body of black limestone and shale, identified by Butts as Whitesburg and Athens.

(11) The typical "Athens" of northern Virginia is a megafacies of the lower Middle Ordovician succession. It ranges downward to the top of the *Dinorthis atavoides* zone and possibly as high as the base of the *Reuschella "edsoni"* zone. The "Chambersburg" limestone, as developed near Lantz Mills, Shenandoah County, comprises another facies. Alternations and lithologic gradations of these two contrasting and equivalent facies are well shown in many sections which have been identified as "typical Chambersburg."

(12) Equivalency of much of the Chambersburg of northern Virginia to the "Whitesburg-Athens" is further indicated by fossils.

(13) It has been assumed, though apparently without justification, that the entire "Athens" of northern Virginia contains the *Nemagraptus gracilis* fauna. Where extended search for *Nemagraptus* in the upper "Athens" has been made in northern Virginia, the genus has not been found. Probably the upper "Athens" includes representatives of the upper, post-*Nemagraptus* zone of the Normanskill, which contains graptolites occurring also in rocks of Chambersburg age.

(14) *Cryptophragmus antiquatus*, long considered a valid guide fossil of the Lowville and Pamelia, occurs not only in the lower *Echinosphaerites* and *Nidulites* zones

(both overlying beds with *Tetradium cellulosum*) but more abundantly in younger beds. The commonly accepted definition of the Chambersburg is that it is younger than the *Cryptophragmus*-bearing "Lowville" limestone of the Appalachian Valley.

(15) The Athens in Virginia, previously regarded as Chazyan, is laterally continuous with beds containing a post-Chazy fauna. Since the Virginia Athens lacks a Chazy fauna, it is reasonable to suppose that it also is post-Chazyan.

(16) The Normanskill shale of New York, faunally and lithologically related to the Virginia Athens, is also probably post-Chazyan, as was originally believed by Ruedemann. The sole basis for placing the Athens-Normanskill in the Chazy was that the Virginia Athens occurs below a *Cryptophragmus*-bearing limestone supposed to be Lowville. Probably the *Cryptophragmus*-bearing zone near the top of the Virginia Chambersburg is at about the same horizon as the so-called Lowville of southwestern Virginia.

(17) Through fossils, the "Chambersburg" beds below the "*Christiania* beds" are linked with Butts' Whitesburg-Athens-Ottosee-Lowville succession in parts of southwestern Virginia.

(18) The true relationships of the "Athens" and "Whitesburg" to the "Chambersburg" in northern Virginia have been previously misunderstood, largely because the facies concept was not adequately considered. The "Athens" is clearly a lithogenic unit transcending faunal or time boundaries. Intertonguing of the two observed facies has been misinterpreted as the unconformable overlapping of one time-stratigraphic unit by another.

(19) A false geologic history of shifting seas and repeated interruptions of marine sedimentation in the Appalachian trough of Middle Ordovician time has been read from previous classifications and correlations. According to the stratigraphic interpretations of the writers, marine deposition in the Appalachian trough was essentially continuous in Middle Ordovician time, although the boundaries of various marine environments shifted from time to time.

Most of the stratigraphic names previously used for parts of the lower Middle Ordovician of the Shenandoah Valley have been employed without proper justification, and their use should be abandoned. It is therefore proposed to reclassify the beds above the Beekmantown and below the Martinsburg into the following ascending divisions:

NEW MARKET LIMESTONE: Includes the body of dove-gray calcilutite succeeding the Beekmantown formation and occurring below dark-gray cherty limestones containing either the *Hesperorthis* fauna or *Dinorthis atavoides* and its associates; the lowest beds may be equivalent to the lower part of the type Lenoir: correlates with the red dolomitic mudrocks and ash-gray shales of the Blackford formation in southwestern Virginia.

WHISTLE CREEK LIMESTONE: Includes the zone herein described as the *Hesperorthis* beds, which occur in the southern part of the Shenandoah Valley, particularly, southeast of Staunton; overlies the New Market and underlies either Murat calcarenites or cherty Lincolnshire limestone with *Dinorthis atavoides*.

LINCOLNSHIRE LIMESTONE: Includes the cherty beds with *Dinorthis atavoides* and *Sowerbyites triseptatus* and the associated intercalations of calcarenite (*Murat cal-*

carenite facies); overlies the Whistle Creek beds in the Lexington-Staunton area; but directly overlies the New Market limestone in middle and northern portions of the Shenandoah Valley.

EDINBURG FORMATION: Chiefly limestone, but includes beds of variable lithology formerly classed as Chambersburg, Whitesburg, and Athens, in the northern part of the Appalachian Valley of Virginia. Two distinct facies are recognizable: a thick body of black limestone and black shale—*Liberty Hall facies*—, mainly developed in the southern part of the Shenandoah Valley, but tongues of which extend as far north as southern Pennsylvania; the other facies is buff-weathering cobbly limestone—*Lantz Mills facies*—, tongues of which extend southward, possibly as far as James River. The characteristically rusty-brown granular beds with trilobites, occurring below Butts' Athens, are named the *Botetourt limestone member* of the Edinburg formation. The distinctive light-gray limestone (calcilutite and calcarenite) above the *Nidulites-Lambeophyllum* zone, between Forestville and Saumsville, Shenandoah County, is named the *St. Luke limestone member*.

ORANDA FORMATION: Composed of 50 feet or less of argillaceous limestone, buff metabentonitic clay, and brown siltstone containing the characteristic *Reuschella "edsoni"* fauna; succeeded by the *Sinuites* beds of the Martinsburg formation. It is widespread on the west side of the Massanutten syncline, at least as far south as Harrisonburg, and possibly extends southward as far as the latitude of Staunton. The age, as established by fossils, is middle Trenton. The Oranda probably corresponds in a general way to the Kimmswick limestone of the Mississippi Valley.

COLLIERSTOWN LIMESTONE: Includes the 50 to 75 feet of calcarenite and intercalated impure limestone and shale which succeeds the Edinburg formation in the extreme southwestern part of the Shenandoah Valley and in the James River district; contains *Zygospira*, *Doleroides*, *Rafinesquina* s.s., and *Parastrophina*. Relations to the Oranda formation are unknown; the Collierstown is confined to areas beyond the southern limits of the Oranda. Fossils signify Trenton age, but the formation may be younger or older than the Oranda, or possibly equivalent to that division

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EXPLANATION OF PLATES

PLATE 2.—MIDDLE ORDOVICIAN FOSSILS

Figure

1–2. *Cryptophragmus antiquatus* Raymond. (1) Large specimen, ×1, U. S. N. M. 111804, found with *Nidulites pyriformis* in the Edinburg formation near Lantz Mills, Shenandoah County (Geologic section 12); (2) specimen ×1, U. S. N. M. 111805, found loose but essentially in place between beds with *Echinosphaerites* and a siltstone containing *Resserella*, Edinburg formation (Geologic section 17).

3–4. *Nidulites pyriformis* Bassler. (3) ×1, U. S. N. M. 111789. From cobbly beds just above the lower *Echinosphaerites* zone of the Chambersburg limestone (Geologic section 8, unit 5), along U. S. Route 40, about 7 miles west of Hagerstown, Maryland. (4) Same, ×1, U. S. N. M. 111806, From Ward Cove limestone at intersection of State Highways 100 and 42, Staffordsville, Giles County, Virginia; also very common in the Ward Cove in eastern Russell and Tazewell counties.

5. *Tetradium syringoporoides* Ulrich, ×1, U. S. N. M. 97378, Dryden, Lee County, Virginia.

6. *Lambeophyllum* sp., ×1, U. S. N. M. 111801. Abundant in *Nidulites* beds of the Edinburg formation; specimen illustrated is from the top division of this formation near Toms Brook, Virginia.

7–8. *Multicostella bursa* (Raymond), ×1, U. S. N. M. 110372a, b. Common in Whitesburg and "Athens" at the Grayson farm, 4 miles southwest of Bland, Bland County, Virginia; also occurs in the lower Edinburg in northern Virginia (Geologic section 40).

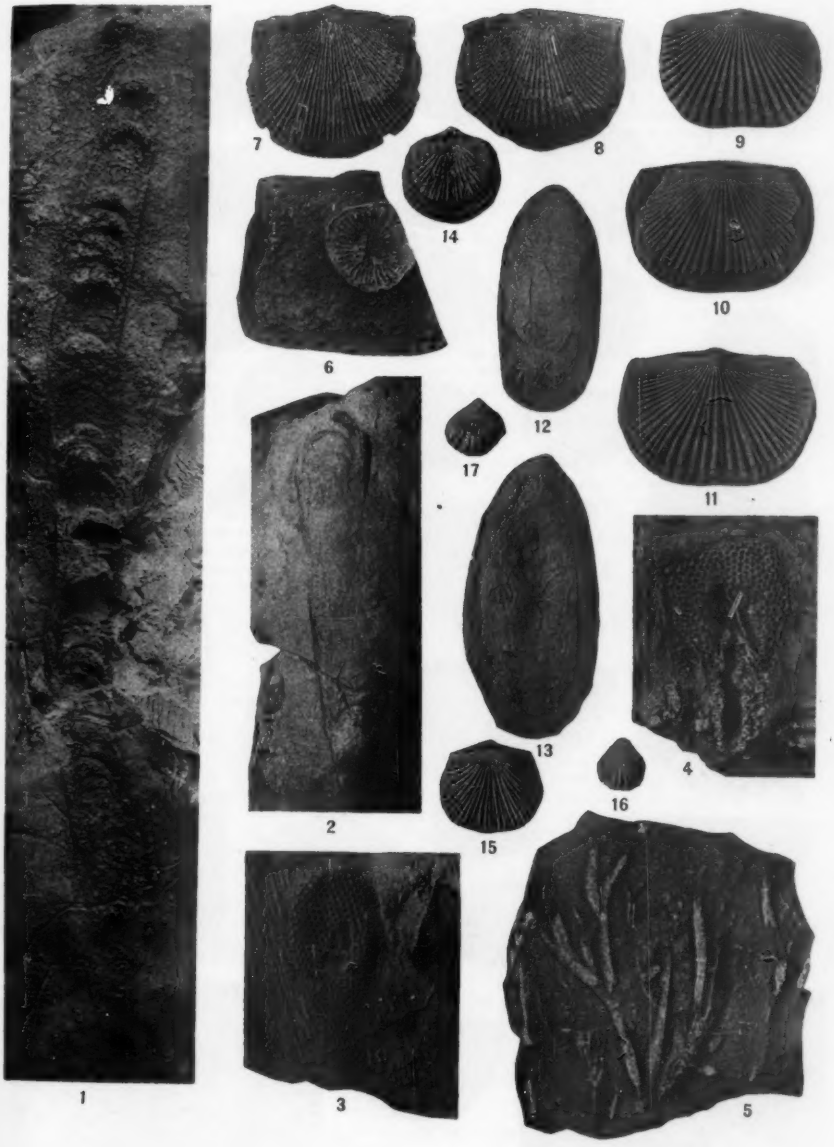
9. *Dinorthis atavoides* Willard, ×1, U. S. N. M. 110283a. Characteristic of the Lincolnshire limestone in Virginia and Tennessee; specimen illustrated is from half a mile northwest of Eidson, Tennessee.

10–11. *Dinorthis transversa* Willard, (10) specimen, ×1, U. S. N. M. 111799, ventral view of an imperfect specimen from lower *Echinosphaerites* zone (unit 2, geologic section 8), along U. S. Route 40, about 7 miles west of Hagerstown, Maryland; (11) perfect specimen, ×1, U. S. N. M. 111800, from lower part of the Benbolt formation, Mt. Hagan School, Hilton quadrangle (TVA), Scott County, Virginia. Found sparingly in the "Athens" 0.25 mile south of Dunkard Church and 6.9 miles S. 80° W. of Natural Bridge, Botetourt County, Virginia (Geologic section 40).

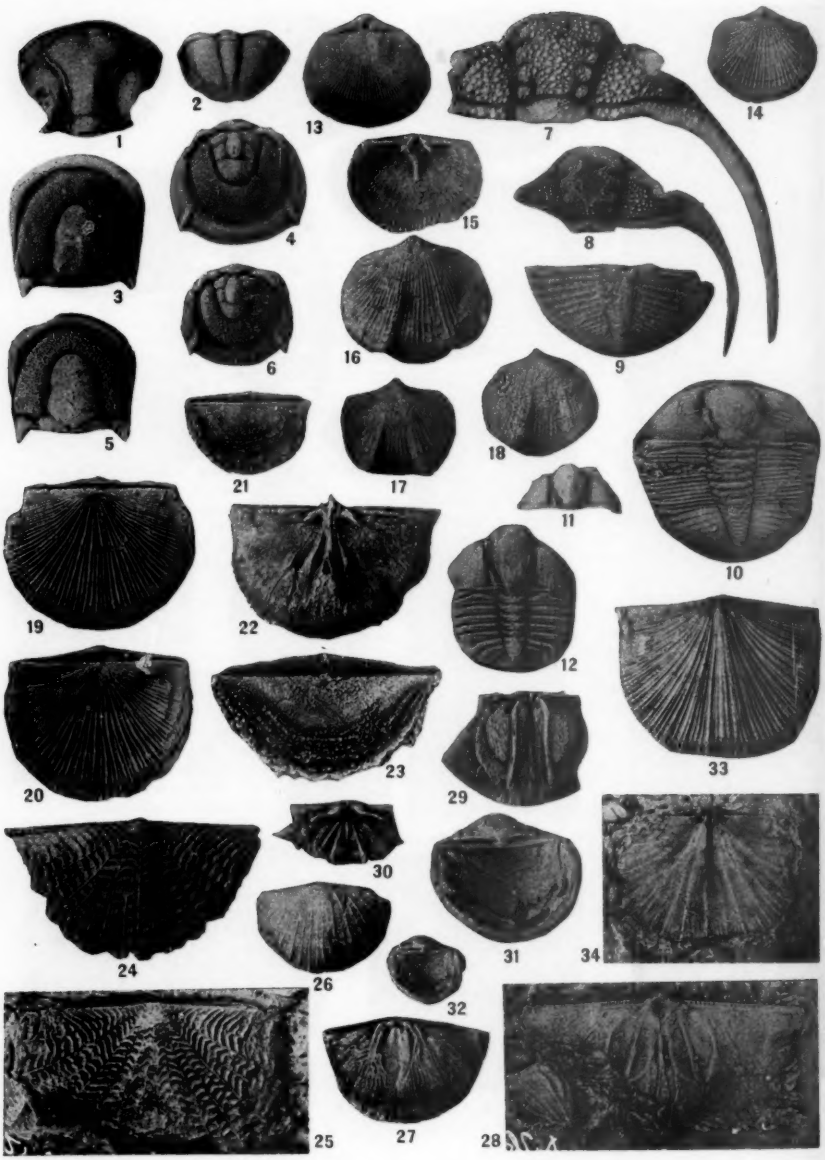
12–13. *Lingula nympha* Raymond (not Billings). Common in the Athens in railway cut at Otes, Tennessee; occurs in beds identified by Butts as Athens at Riverton, Warren County, Virginia; (12), ×1, U. S. N. M. 109287c; and (13) from 300 feet west of Route 3, three fourths of a mile northeast of Ninevah, Virginia, ×1, U. S. N. M. 109293.

14–15. *Resserella* cf. *R. rogata* (Sardeson), ×1, U. S. N. M. 111794 (14) specimen, ×2, U. S. N. M. 111794, from Athens limestone, Sharon Springs, Bland County; and (15) ×2, U. S. N. M. 111795, from lower cobbly beds (Lantz Mills facies) of the Edinburg formation, a quarter of a mile east of Strasburg Junction (Geologic section 19), Shenandoah County.

16–17. *Rostricellula pristina* (Raymond) (16) ×1, U. S. N. M. 111793a, from basal calcarenite in the New Market limestone; northeast of Staunton (Geologic section 33), Augusta County; (17), ×1, U. S. N. M. 111520b, from base of type Lenoir limestone, Lenoir City, Tennessee.



MIDDLE ORDOVICIAN FOSSILS



MIDDLE ORDOVICIAN FOSSILS

PLATE 3.—MIDDLE ORDOVICIAN FOSSILS

Figure

1–2. *Bronteopsis gregaria* Raymond. Common in Whitesburg and Athens limestone. (1) Imperfect cranidium, ×2, U. S. N. M. 72527a; (2) pygidium, ×2, U. S. N. M. 72527b, Reservoir Hill, Lexington, Virginia.

3–6. *Arthrorhachis elspethi* Raymond. (3–4) head, U. S. N. M. 111782b, and tail, ×3, U. S. N. M. 111782a, from bed containing *Cyrtonotella* in the lower *Echinosphaerites* beds of the Edinburg formation (Geologic section 19, unit 18), a quarter of a mile east of Strasburg Junction, Shenandoah County. This fossil is one of the characteristic species in Butts' Whitesburg limestone; (5–6) same, from *Nidulites* beds of the Edinburg formation, along U. S. Route 11, about 1 mile north of Strasburg, Shenandoah County, ×3, specimens unnumbered.

7–8. *Ceraurus pleurexanthemus* Green. (7) From *Nidulites* beds of the Edinburg formation, along U. S. Route 11, about 1 mile north of Strasburg, ×2, U. S. N. M. 111783; (8) from bed with *Cyrtonotella* (Geologic section 19, unit 18), at base of Edinburg formation, a quarter of a mile east of Strasburg Junction, ×2, U. S. N. M. 111784.

9–10. *Dionide holdeni* Raymond. (9) Large pygidium from granular limestone of lower *Echinosphaerites* beds of the Edinburg formation, 3½ miles south of Wadesville, Clarke County, Virginia, ×1, U. S. N. M. 111785; (10) nearly complete specimen from the "Athens" shale, old limestone quarry 2½ miles southeast of Saltville, Virginia, ×1, U. S. N. M. 111786.

11–12. *Ampyxina scarabeus* Butts. Genus occurs throughout the "Chambersburg" and "Athens" formations. (11) from "Whitesburg" limestone, 4 miles south of Bland, Virginia, ×3, U. S. N. M. 72139; (12) complete specimen from Athens, State Route 114, 4–5 miles southwest of Catawba Sanatorium, Roanoke Co., ×3, U. S. N. M. 97434b.

13–15. *Corineorthis* sp. (13) Large species common in the lower cobbly beds of the Edinburg formation, half a mile north of Glendale School, Winchester quadrangle, Virginia ×1, U. S. N. M. 111787; (14–15) dorsal view and dorsal interior of another species, "Whitesburg" limestone, Porterfield Quarry, 5 miles east of Saltville, Virginia, ×2, U. S. N. M. 111802. This genus has been collected from the type Chambersburg (*Echinosphaerites* zone) and from Butts' Chambersburg, Whitesburg, and Athens in Virginia.

16–18. *Oxoplecia* cf. *O. simulatrix* (Bassler). (16) From lower part of the Benbolt formation 1½ miles south of Hansonville, Russell County, Virginia, ×1, U. S. N. M. 111990; (17) from lower *Echinosphaerites* beds of the Edinburg, half a mile east of Strasburg Junction, ×1, U. S. N. M. 111792; (18) from "Athens" limestone, 1.5 miles S. 15° W. of Sharon Springs, Bland County, Virginia, ×1, U. S. N. M. 111791.

19–20. *Cyrtonotella* sp. (19) from lower part of Benbolt formation, half a mile east of Cedar Point School, Russell County, Hilton quadrangle (TVA) ×1, U. S. N. M. 111803; (20) abundant in lower *Echinosphaerites* zone of the Edinburg formation, a quarter of a mile east of Strasburg Junction, ×1, U. S. N. M. 109860a.

21–23. *Sowerbyites triseptatus* (Willard). A characteristic fossil of the Lincolnshire limestone of Virginia and Tennessee. (23) exterior, ×2, Marcem Quarry, 2 miles W. of Gate City, Virginia, U. S. N. M. 111797a; (22) dorsal interior, ×2, showing strong medium septum; (21) exterior, ×1, showing exterior lamellae, both from Lincolnshire limestone in Clinch Valley at Shiloh Church, Pressmans Home Quadrangle, Tennessee, U. S. N. M. 111796a.

24–25. *Ptychoglyptus virginiensis* Willard. (24) Fine specimen from "Athens" limestone (Liberty Hall facies of the Edinburg formation) (Geologic section 24, unit 6), 6 miles east of Harrisonburg, ×2, U. S. N. M. 98231; (25) from *Cyrtonotella* bed near base of the Edinburg formation, a quarter of a mile east of Strasburg Junction, ×2, U. S. N. M. 111052.

26–28. *Eoplectodonta alternata* (Butts). (26) Ventral exterior, ×1, U. S. N. M. 79419a, Oranda formation, half a mile west of Strasburg, Virginia; (27) Ventral interior, ×1, U. S. N. M. 110993a; (28) dorsal interior, ×3, U. S. N. M. 110993b, showing hinge denticles. Characteristic of the Oranda formation, both from 0.5 mile west of Linville Station, Rockingham County, Virginia.

29–32. *Bimuria lamellosa* (Bassler). (29, 30) Dorsal interior and dorsal hinge views, ×2, U. S N. M. 110948a; (31) dorsal view, ×2; (32) same, ×1, U. S. N. M. 66168a. Oranda formation 0.5 mile west of Strasburg, Virginia. This is the species for which the "*Christiania*" bed of the Chambersburg was named. *Bimuria* differs from *Christiania* in having two, instead of four, long septa in the dorsal interior, in having a simple cardinal process, and a hinge width comparable to the length of the shell.

33–34. *Reuschella "edsoni"* Bassler. (33) ventral exterior, ×1, U. S. N. M. 110840b; (34) impression of dorsal interior, ×1, U. S. N. M. 110840i; Oranda formation, 0.5 mile northwest of Linville Station, Rockingham County.

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CONTRIBUTION TO THE PETROGRAPHY OF HALEAKALA VOLCANO, HAWAII

BY GORDON A. MACDONALD AND HOWARD A. POWERS

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ABSTRACT

The volcanic rocks of Haleakala Volcano comprise, from oldest to youngest, the Honomanu, Kula, and Hana volcanic series. The Honomanu volcanic series consists largely of olivine basalt, with less abundant basalt and picrite-basalt containing large phenocrysts of olivine. In the Kula and Hana volcanic series there are some basalts and olivine basalts, but the characteristic rocks are andesites and picrite-basalt containing abundant phenocrysts of augite as well as olivine. New chemical analyses of six specimens of Kula lavas are given. Five are andesites, and one a picrite-basalt. Each of the six rocks is described in detail. A variation diagram for Haleakala rocks illustrates the alkalic character of the series.

INTRODUCTION

The purpose of this paper is to make available to petrologists six new chemical analyses and petrographic descriptions of rocks of Haleakala Volcano, Hawaii. To make clear the position of the analyzed rocks in the eruptive sequence of the volcano, the general geology and petrography of the mountain are briefly reviewed.

The analyses were made possible by a grant from the Penrose Bequest of The Geological Society of America to the Committee on Hawaiian Petrology, consisting of C. K. Wentworth, W. O. Clark, H. S. Palmer, H. A. Powers, and Horace Winchell. The specimens were collected and prepared for analysis in 1940 by Powers, who also made brief preliminary petrographic examinations. Since the completed analyses were received, in 1942, Powers has, however, been too fully occupied with military duties to do any further work on the project, and a recent change of station makes it unlikely that he would be able to do any for some time. For that reason, in October 1944 the Committee requested Macdonald to complete the study of the rocks and prepare a report for publication.

The rocks have been studied principally in thin section. Statements of size of optic axial angles are estimates based on the appearance of optic-axis or acute-bisectrix interference figures. Feldspar compositions are based partly on extinction-angle methods but principally on the refractive index determined by immersion methods. The refractive indices are probably accurate within .003.

GEOLOGIC SETTING

Haleakala Volcano forms the eastern part of the island of Maui, in the Hawaiian Islands. The visible rocks of the volcano are largely lavas; pyroclastic and intrusive rocks form only a very small proportion. The lavas range in composition from picrite-basalt to oligoclase andesite. They have been divided into three main groups (Stearns and Macdonald, 1942, p. 61–107). The oldest constitute the Honomanu volcanic series and consist very largely of olivine basalt, with smaller amounts of basalt (containing less then 5 per cent olivine) and picrite-basalt rich in phenocrysts of olivine. The Honomanu lavas closely resemble those of Kilauea and Mauna Loa volcanoes on the island of Hawaii, and the early lavas of other Hawaiian volcanoes (Powers, 1935, p. 62). In the uppermost part of the Honomanu volcanic series, near Nahiku (Stearns and Macdonald, 1942, p. 233–234), there appear olivine basalts transitional toward picrite-basalts, which contain numerous phenocrysts of augite.

The Honomanu volcanic series is in places separated from the overlying Kula volcanic series by a thin bed of red tuffaceous soil, but elsewhere they grade into each other. There is no real break between the two, and their separation is based principally on petrographic differences. The lavas of the Kula volcanic series include olivine basalt, basalt, picrite-basalt, and andesite. The most characteristic rock type is the andesite, which forms thick massive flows contrasting markedly with the typically thin-bedded flows of the Honomanu volcanic series. The predominant feldspar of most of the andesites is andesine, but in a few it is oligoclase. Most of the andesites are basaltic both in their habit and in the abundance of mafic minerals. The picrite-basalts contain numerous phenocrysts of both olivine and augite, generally in roughly equal abundance.

The Kula volcanics are locally separated from the later Hana volcanic series by a profound erosional unconformity (Stearns and Macdonald, 1942, p. 89). A great decrease of volcanism permitted the cutting by streams of huge valleys, several thousand feet deep, into the Kula and Honomanu volcanics. It appears unlikely, however, that volcanism entirely ceased, and the unconformity probably does not represent precisely the same age horizon at all places on the mountain. The Hana volcanic series includes the same general types of lava as the Kula volcanic series, but olivine basalt is relatively more abundant, and no andesites have been found which are as salic as some of those among the Kula lavas.

In the walls of the great depression which occupies the summit region of the mountain, commonly known as Haleakala Crater, lavas of the Kula volcanic series are extensively exposed. The floor of the depression has been buried by lavas and cinder cones of the Hana volcanic series, which also cover part of the walls.

Only one eruption of Haleakala Volcano has occurred within the range of native tradition. That took place low on the southwest rift zone, about 1750 (Fig. 1). One

FIGURE 1.—*Geologic map of Haleakala Volcano*

Showing the localities at which the analyzed specimens were collected. The geology is generalized, and small amounts of sedimentary rocks omitted. The road from Kahului to the summit is shown for reference to the specimen localities. (After Stearns and Macdonald, 1942, Pl. 1.)

flow issued from a fissure at 1200 feet altitude, and another at Kaluaolapa Crater, at 575 feet altitude. The lava is a picrite-basalt, containing numerous phenocrysts of olivine and augite. A specimen collected by Sidney Powers (1920, p. 265) and analyzed by Washington and Keyes (1928, p. 213–215), has been shown almost certainly to have come from the historic flow from Kaluaolapa Crater (Macdonald, 1942a, p. 302).

DESCRIPTION OF ANALYZED SPECIMENS

All the lavas of which new analyses are presented belong to the Kula volcanic series. Four of them were collected at or near the western rim of Haleakala Crater, and the other two on the western flank of the mountain (Fig. 1). Extensive search by Powers yielded no samples of Honomanu lavas fresh enough for analysis.

SPECIMEN 1: The rock is a picrite-basalt very rich in large phenocrysts of olivine and augite. The specimen was collected at the lowest point of the east-facing cliff, at 9500 feet altitude, 0.3 mile north of Pakaoa Hill at the southwestern corner of Haleakala Crater. The flow is that which supplied the augite crystals analyzed by Washington and Merwin (1922).

The rock is a dark-gray aa, containing numerous phenocrysts of brownish-green olivine and black augite up to 1 cm. long. A microscopic analysis by the Rosiwal method shows that the augite phenocrysts make up 21 per cent, and the olivine phenocrysts 20.5 per cent of the rock by volume. Rare phenocrysts of bytownite also are present. The composition and properties of the augite were determined by Washington and Merwin (1922). The properties, as stated by them, are: $2V = 61°–62°$, $2V$ for blue $= 58°–60°$; $Z \wedge c = 47°–48°$ for red, 49° for blue; $\alpha = 1.700$, $\beta = 1.706$, $\gamma = 1.724$; density $= 3.358$. Many grains show a narrow outer zone in which the extinction angle is less than in the core, and the $2V$ decreases to about 35°. The olivine phenocrysts have an optic axial angle close to 90°, and $\beta = 1.699$. Many are slightly altered around the edges to iddingsite. Most of the olivine and augite phenocrysts are rounded by magmatic resorption. One partly resorbed phenocryst of magnetite 1 mm. across was observed. Small grains of magnetite are enclosed in the olivine phenocrysts, and both magnetite and olivine are enclosed in the augite phenocrysts.

The groundmass is intersertal to intergranular, with an average grain size of about 0.03 mm. It is too fine-grained and confused to permit accurate determinations of mineral proportions by the Rosiwal method, but the estimated proportions (per cent) are: plagioclase 25, monoclinic pyroxene 18, olivine 5, iron ore 9, glass 1, apatite < 1. The plagioclase is principally medium labradorite, with a few interstitial grains of oligoclase. The oligoclase appears to have a small optic axial angle and is probably potassic (Macdonald, 1942b). The pyroxene is pigeonite, with a small positive optic axial angle. Only a few grains are large enough to yield good optic figures, but in most of these the $2V$ is near 0°. The iron ores are largely or entirely magnetite. (*See* Table 1 for chemical analyses.)

SPECIMEN 2: The rock is an andesite, with a decidedly basaltic aspect. The specimen was collected from a road cut at 8900 feet altitude, about 0.3 mile north of the Summit Rest House. The lava is dark gray and dense, with a few phenocrysts of olivine and augite and a very few of feldspar, up to 5 mm. long. Phenocrysts of all

TABLE 1.—*Chemical analyses of rocks from Haleakala Volcano*

	1	2	3	4	5	6	7
SiO_2	42.30	46.90	46.94	47.64	47.78	54.14	47.70
Al_2O_3	10.52	16.60	16.54	17.62	16.32	17.82	6.82
Fe_2O_3	4.22	4.37	5.31	5.62	4.37	3.90	3.36
FeO	9.70	7.16	7.16	5.48	8.43	5.34	4.43
MgO	14.90	4.35	4.33	4.19	5.06	1.88	13.34
CaO	12.08	8.50	8.34	7.90	7.58	4.94	21.35
Na_2O	1.56	4.51	4.27	4.72	4.18	6.24	0.65
K_2O	0.42	2.38	1.49	1.60	1.30	2.72	0.03
TiO_2	2.41	3.92	4.05	3.44	4.11	1.81	1.89
MnO	0.06	0.07	0.07	0.08	0.08	0.08	0.16
BaO	none	none	none	none	none	none	—
SrO	none	none	none	none	none	none	—
H_2O^+	0.87	0.20	0.46	0.45	0.37	0.24	0.15
H_2O^-	0.45	0.04	0.05	0.09	0.06	0.03	—
CO_2	none	none	none	none	none	none	—
P_2O_5	0.33	0.79	0.71	0.87	0.61	0.61	—
SO_3	none	0.02	0.03	0.03	0.02	0.04	—
Cr_2O_3	0.11	none	none	none	none	none	0.23
Total	99.93	99.81	99.75	99.73	100.27	99.79	100.11
NORMS							
Or	2.22	13.90	8.90	9.45	7.78	16.12	—
Ab	7.34	25.15	32.49	34.06	35.11	46.11	—
An	20.57	18.07	21.41	25.85	21.68	12.51	—
Ne	3.12	7.10	1.99	3.12	0.28	3.69	—
Di Wo	15.66	7.77	6.50	3.25	5.22	3.48	—
Di En	11.10	5.60	4.90	2.80	3.50	1.90	—
Di Fs	3.17	1.45	0.92	—	1.32	1.45	—
Ol Fo	18.27	3.64	4.13	5.39	6.37	1.96	—
Ol Fa	5.61	1.22	1.02	—	2.86	1.63	—
Mt	6.03	6.50	7.66	7.66	6.50	5.57	—
Il	4.56	7.45	7.60	6.54	7.75	3.50	—
Ap	0.67	2.02	1.68	2.02	1.34	1.34	—
Hm	—	—	—	0.32	—	—	—

1. Picrite-basalt, from the lowest point of the east-facing cliff, at 9500 feet altitude, 0.3 mile north of Pakaoa Hill. F. A. Gonyer, analyst.

2. Andesite, from road cut at 8900 feet altitude, 0.3 mile north of the Summit Rest House. F. A. Gonyer, analyst.

3. Andesite, from County quarry, on the bank of Kalialinui Gulch half a mile west of Puu Pane. F. A. Gonyer analyst.

4. Andesite, from 6-foot dike in face of Kalahaku cliff, 0.45 mile N. 80° E. of Kilohana triangulation station. F. A. Gonyer, analyst.

5 Andesite, from Hawaiian Commercial and Sugar Co. quarry near the road from Kahului to the summit of Haleakala, 3.6 miles southeast of Kahului. F. A. Gonyer, analyst.

6. Oligoclase andesite, from the western rim of Haleakala Crater, 0.6 mile northwest of the Summit Rest House. F. A. Gonyer, analyst.

7. Augite, phenocrysts from same flow as specimen 1. H. S. Washington, analyst.

three types are partly resorbed. Those of olivine have 2V close to 90°, and β = 1.696. Those of augite have $+2V = 60°$, strong inclined dispersion, and $\beta = 1.717$. The plagioclase phenocrysts are zoned from sodic bytownite in the center to sodic

labradorite on the margins. Microphenocrysts of magnetite up to 0.15 mm. across also are present.

The groundmass is intergranular, with an average grain size of about 0.02 mm. The groundmass feldspar consists partly of subhedral laths of sodic labradorite, and partly of anhedral andesine, the latter being the more abundant. Much of the andesine has a small +2V and is probably potassic. This supposition is strengthened by the large amount of orthoclase in the norm, which cannot otherwise be identified in the mode. The iron ore is largely magnetite but probably includes some ilmenite. The pyroxene grains are too small to yield useful interference figures. The extremely fine granularity and partial overlapping of grains in the groundmass makes impossible any accurate determination of the proportions of the various minerals, and distinctions between microphenocrysts and groundmass are arbitrary. However, the approximate proportions are as follows:

		Per cent			Per cent
Phenocrysts and microphenocrysts	olivine	5	Groundmass	plagioclase	45
	augite	1		monoclinic pyroxene	26
	plagioclase	5		olivine	5
	magnetite	2		iron ore	10
				apatite	1

SPECIMEN 3: The rock is an andesine andesite, collected at the County quarry on the lower Kula road on the bank of Kalialinui Gulch, half a mile west of Puu Pane. It is medium gray and dense, with rare phenocrysts of feldspar up to 1 cm. long and of olivine up to 1.5 mm. long. The phenocrysts, and microphenocrysts of monoclinic pyroxene up to 0.6 mm. long, grade into the groundmass. The feldspar phenocrysts are zoned from labradorite-andesine in the center to sodic andesine on the margins. The pyroxene is pale purplish-brown pigeonitic augite (Macdonald, 1944), with a +2V of about 45°, moderately strong inclined dispersion, and poorly developed hourglass structure. It is probably titaniferous.

The groundmass is intergranular to intersertal, with an average grain size of about 0.04 mm. It is composed of plagioclase, pigeonite, olivine, iron ore, minute grains of apatite, a little pale-brown interstitial glass, and locally a little interstitial chloritic material. The plagioclase has the refractive index of sodic andesine ($\beta = 1.551$), but many grains have a small +2V and are probably potassic. The iron ore is largely or entirely magnetite.

The estimated composition (per cent) of the rock, including phenocrysts, is: plagioclase 60, pyroxene 21, olivine 2, iron ore 15, apatite 1, glass < 1, chlorite < 1.

SPECIMEN 4: The specimen was collected from a 6-foot dike at the top of a prominent knob on the face of the Kalahaku cliff, at 8900 feet altitude, 0.45 mile N. 80° E. of the Kilohana triangulation station. The rock is an andesite. It is medium gray and nonporphyritic, with a few vesicles less than 1 mm. across. The texture is intergranular, and the average grain size is about 0.2 mm. The volumetric percentages of the constituent minerals, determined by the Rosiwal method, are: plagioclase 74.1, pyroxene 11.1, olivine 3.9, iron ore 8.0, biotite 1.1, and apatite 1.8. Microphenocrysts of plagioclase, up to 1 mm. long, are zoned from labradorite-andesine in

the center to calcic oligoclase on the margins. The groundmass feldspar ranges from medium andesine to medium oligoclase. The latter has a $+2V$ of about 40° and is probably potassic. The average composition of the plagioclase is probably sodic andesine. The olivine is slightly altered to iddingsite around the edges and along fractures. The pyroxene is augite, with $+2V = 50°\pm$, and weak dispersion. The iron ore is largely, if not entirely, magnetite. Apatite forms unusually large prismatic crystals, some of which are as much as 1 mm. long and 0.1 mm. wide. The biotite is strongly pleochroic, with X = very pale yellow, Z = deep reddish-brown, $-2V = 20°\pm$, and $r < v$ distinct. A few grains of biotite are subhedral, but most are anhedral, molded around the other minerals. As in other Hawaiian lavas (Macdonald, 1940, p. 68), it obviously formed very late in the period of crystallization of the rock.

SPECIMEN 5: The specimen was collected from the quarry of the Hawaiian Commercial and Sugar Co., near the road from Kahului to the summit of Haleakala, at about 250 feet altitude, 3.6 miles southeast of Kahului. The rock is an andesite. It is medium gray and dense, essentially nonporphyritic, but with very rare phenocrysts of olivine up to about 1 mm. long. The texture is intergranular and locally slightly ophitic, and the average grain size is about 0.07 mm. The approximate mineral composition (per cent) is: plagioclase 53, pyroxene 24, olivine 10, iron ore 12, apatite 1, and biotite < 1. The plagioclase is zoned from calcic andesine to medium oligoclase; a few of the largest grains have cores of sodic labradorite. The composition of the plagioclase averages sodic andesine. The olivine has a negative sign and an optic axial angle close to 90°. The pyroxene is augite, with $+2V = 60°\pm$, and weak dispersion. The biotite is brown with a slightly purplish tinge and crystallized late. The iron ore includes both ilmenite and magnetite, the latter being apparently the more abundant.

One of the four slides examined contains a little calcite. The other three contain none, and the lack of CO_2 in the analysis indicates that very little or none was present in the sample analyzed. In the slide containing it, the calcite is almost entirely confined to zones less than 1 mm. wide, parallel to the poorly defined fluidal structure. It occupies irregular interstices between the other minerals, corresponding in position to late-crystallized feldspar in the rest of the rock. No alteration of the associated minerals could be detected. The calcite is probably primary, formed in a very late stage. A similar rock containing calcite which appears to be of primary origin was found on West Maui Volcano (Macdonald, 1942a, p. 316–317).

SPECIMEN 6: This rock is a hornblende-bearing oligoclase andesite and is more salic than any other rock from Haleakala Volcano thus far analyzed. The specimen was collected on the western rim of Haleakala Crater at an altitude of 8700 feet, at the top of Leleiwi Pali (cliff) and 0.6 mile northeast of the Summit Rest House. The rock is medium gray and dense, with a few tabular phenocrysts of feldspar up to 7 mm. long, and rare small phenocrysts of hornblende. The presence of hornblende is in itself sufficient to make the rock remarkable, as it is found in only a few Hawaiian lavas. It is basaltic hornblende, pleochroic from brownish yellow to deep greenish brown. The feldspar phenocrysts are sodic labradorite, partly resorbed. One of the three slides studied contains a single phenocryst of a riebeckite-like amphibole, resembling that in the oligoclase andesites and trachytes of West Maui Volcano (Macdonald, 1942a, p. 322).

The groundmass consists largely of poikilitic grains of feldspar containing smaller included grains of monoclinic pyroxene, olivine, iron ore, and apatite. Fluidal structure is locally well developed. The larger feldspar grains are zoned from medium andesine to medium oligoclase. The predominant feldspar is medium oligoclase

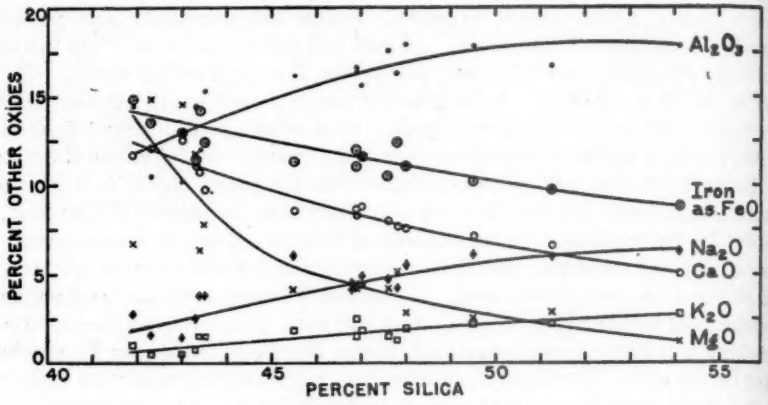

FIGURE 2.—*Variation diagram of lavas of Haleakala Volcano*

(β = 1.542). The optic axial angle of the feldspar is large, probably near 75°, but the sign is positive, which is abnormal for plagioclase with this refractive index. In view of the large amount of orthoclase in the norm, it is believed that the oligoclase is potassic. A few small grains of feldspar with refractive index decidedly less than 1.54 are probably potash feldspar. The grains of pyroxene are too small to yield useable interference figures. The iron ore is largely or entirely magnetite. A very few tiny flakes of brown biotite are present. The approximate proportions (per cent) of the various minerals are: hornblende < 1, plagioclase phenocrysts < 1, groundmass feldspar 55, pyroxene 28, olivine 4, iron ore 12, apatite 1, and biotite < 1.

CHEMICAL ANALYSES

In Table 1, columns 1 to 6 show the analyses of the specimens described. Column 7 shows the analysis of augite phenocrysts from the same flow as specimen 1 (Washington and Merwin, 1922).

Analysis 1, of picrite-basalt, closely resembles that of a similar augite-rich picrite-basalt in the Hana volcanic series, collected by Cross (1915, p. 29) at the base of Namanaokeakua Cone in Haleakala Crater. Analyses 2 to 5 are similar to analyses of other andesine andesites of Haleakala (Macdonald, 1942a, p. 309), and of Mauna Kea (Macdonald, in preparation; Washington, 1923, p. 490, 493). Analysis 6, of oligoclase andesite, falls within the range of composition of oligoclase andesites of Kohala Volcano, on the island of Hawaii (Macdonald, in preparation; Washington, 1923, p. 478), but is poorer in silica and alkalies than the single analyzed specimen of oligoclase andesite from West Maui Volcano (Macdonald, 1942a, p. 334). Nepheline

is present in the norms of all six specimens, but in none of them has there been found modal nepheline or any other silica-deficient mineral except olivine.

In Figure 2 are plotted all the available chemical analyses of lavas of Haleakala Volcano. The earlier analyses have been summarized elsewhere (Macdonald, 1942a, p. 309). The alkali-lime index (the silica percentage at which the sum of potash plus soda equals the percentage of lime) is 48.7, placing the rock series in the alkalic group (Peacock, 1931).

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